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**THESIS**

Application of Voice Recognition  
Input to Decision Support Systems

by

Robert Gervase Drake

December 1988

Thesis Advisor:

Judith H. Lind

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Application of Voice Recognition  
Input to Decision Support Systems

by

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Submitted in partial fulfillment of the requirements for  
the degree of

**MASTER OF SCIENCE IN INFORMATION SYSTEMS**

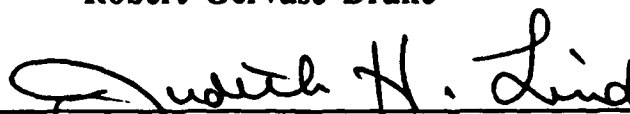
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## ABSTRACT

The goal of this study is to provide a single source of data that enables the selection of an appropriate voice recognition (VR) application for a decision support system (DSS) as well as for other computer applications. A brief background of both voice recognition systems and decision support systems is provided with special emphasis given to the dialog component of DSS. The categories of voice recognition discussed are human factors, environmental factors, situational factors, quantitative factors, training factors, host computer factors, and experiments and research. Each of these areas of voice recognition is individually analyzed, and specific references to applicable literature are included.

This study also includes appendices that contain:

- A glossary (including definitions) of phrases specific to both decision support system and voice recognition systems,
- Keywords applicable to this study,
- An annotated bibliography (alphabetically and by specific topics) of current VR systems literature containing over 200 references,
- An index of publishers, and
- A complete listing of current commercially available VR systems.



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## **I. INTRODUCTION**

### **A. BACKGROUND**

The rapid influx of powerful microcomputers has provided both the incentive and capability to enhance the productivity of humans. These powerful and inexpensive workhorses are being exploited for automating routine tasks, acquiring and communicating information, and the intelligent support of decision making. Of major importance is the effort to enhance the productivity of humans who control these machines through the use of human-computer interfaces that both maximize human performance and take advantage of the growing capabilities of these computer systems.

It is estimated that, for over 95 percent of human-computer interactions, people costs are greater than the machine costs [Infotech 79]. Actions that reduce the human cost and simplify the human interface will have great impact on the computer industry. A technology must explore these interfaces in order to grow and develop to its full potential.

Many forms of man-machine interfaces have been developed, including cathode ray tube displays, printers, keyboards, joysticks, etc. However, speech is recognized to be the most natural and fastest form of human communication, and should be considered as an interface technique for system optimization. [LeFever 87]

Research into voice recognition (VR) systems has been ongoing for over 30 years. Research into decision support systems (DSS), which evolved from management information systems over 15 years ago, now is maturing. The two

technologies, which until now have matured separately, are logical candidates for merging. Thus the focus of this study is the application of voice recognition systems to decision support systems. A Glossary of Terms used in this study is provided in Appendix A.

## **B. VOICE RECOGNITION SYSTEMS**

Voice recognition is defined as the ability of a computer or other device to recognize spoken words correctly and to translate them into a predetermined output string to the computer [LeFever 87]. Voice recognition is also called automatic speech recognition and by other names, as listed in Appendix B. It is important to note that the term voice recognition refers to and concerns only command input via the human voice. It does not include computerized voice output or speech synthesis.

There are many advantages to using voice input to computer systems. In general, a voice recognition system:

- is more accurate than conventional forms of input
- allows for concurrent use of hands, eyes, and other senses
- allows freedom of movement from a specified location
- can be used in low light or dark areas
- is faster than conventional forms of input
- promotes the use of the computer system or application that it is used in conjunction with
- is easy to learn and easy to use
- promotes productivity
- works better in multilingual environments than conventional input
- works equally well for individuals ranging from novice typists through expert typists
- works well for many handicapped individuals [Poock 80, Poock 81, Armstrong 80, Baker 84, LeFever 87]

Dobney classifies voice recognition as "a fifth generation language or more concisely a fifth generation concept." [Dobney 87] Voice recognition, along with other fifth generation concepts, is expected to be critical for the future for all computer applications.

### **C. DECISION SUPPORT SYSTEMS**

There is no generally recognized single definition of decision support systems. The definitions in use cover a broad spectrum of what is and is not a DSS [Keen 87]. For this study, the following definition will be used:

The application of available and suitable computer-based technology to help improve the effectiveness of managed decision making in semi-structured tasks. [Keen 87]

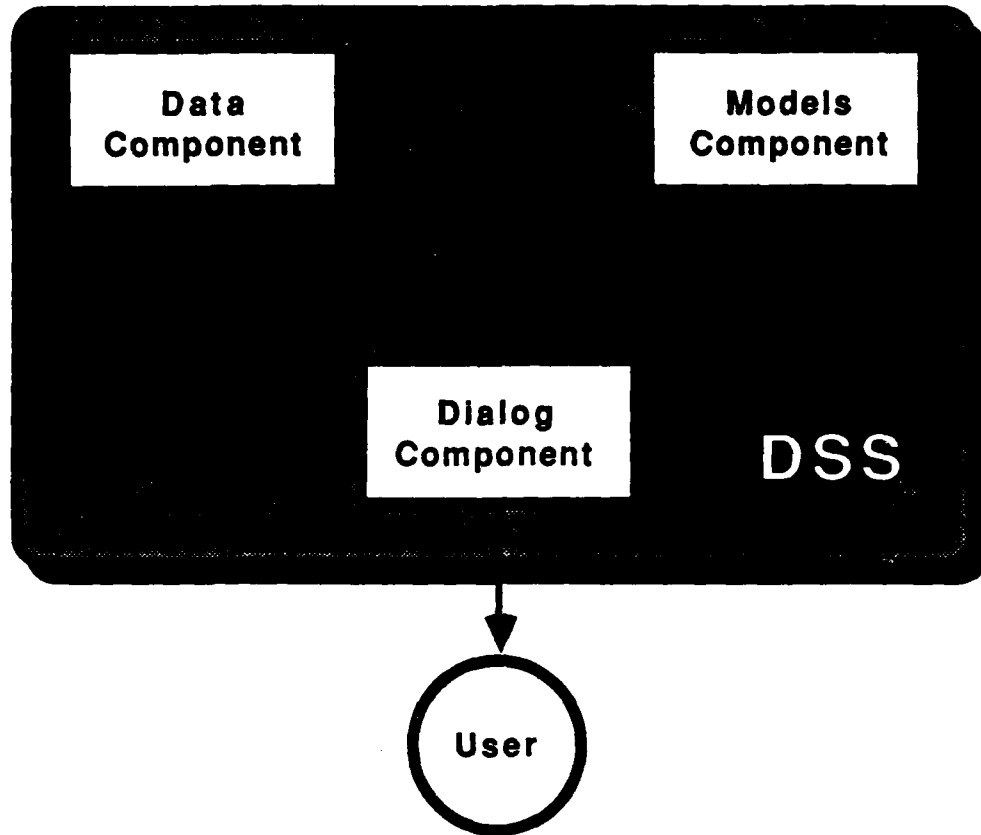
The key aspects of DSS include:

- They are computer based systems.
- They are used by decision makers.
- They help decision makers confront ill-structured problems.
- They work through direct interaction.
- They utilize data analysis models. [Sprague 82]

This study will focus on the fourth aspect, direct interaction between the decision maker and the computer system.

The basic DSS has three components: data, dialog, and models [Sprague 82]. These are referred to as the DDM paradigm of a DSS and the relationships are illustrated in Figure 1.1. The importance of the dialog component cannot be over-emphasized, since all the capabilities of the DSS must be articulated and implemented through it.

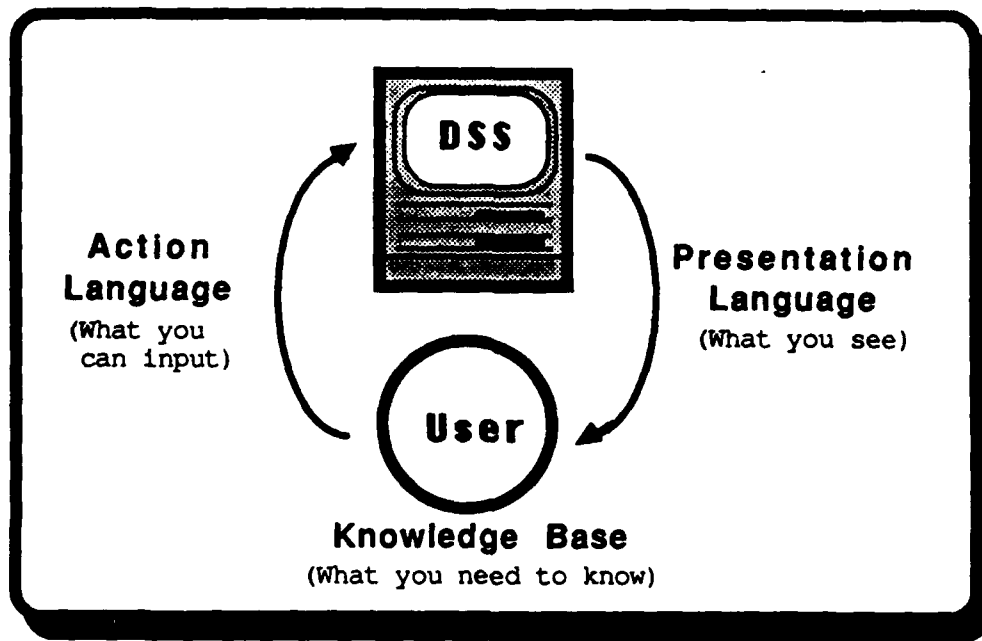
## **(Dialog-Data-Model) DDM Paradigm**



**Figure 1.1. The Dialog, Data, Model Components of the DSS Framework [Sprague 82]**

This dialog component consists of three subcomponents, as illustrated in Figure 1.2.

- The action language is what the user can do in communicating with the system.
- The presentation or display language is what the user sees.
- The knowledge base is what the user must know in order to operate the system. This can take the form of help menus, reference cards or instructions, a user's manual or information that previously has been learned.



**Figure 1.2. The Dialog System User Interface [Sprague 80]**

This study primarily considers the action language of DSSs and its implementation through the use of voice input. Secondary consideration is given to minimizing the size of the knowledge base through the use of a natural language interface and by optimizing the presentation language so that it will naturally encourage and prompt proper input.

No single all-encompassing or overall best dialog mode presently exists. That is, no system has the ability to handle a variety of human interaction styles, shifting between styles at the user's request. Regardless of a user's experience with computers or the problem or tasks, the specific dialog mode of a given system must be learned and used, in order to use the system. This is true even if the user is already familiar with another dialog mode for another system.

As noted by Sprague, "Dialog will profit significantly from the inclusion of natural language processing techniques and voice recognition." [Sprague 87]

## **D. GOALS AND OBJECTIVES**

The primary objective of this study is to provide a current, concise, condensed, and summarized single source of data that will enable selection of an appropriate voice recognition application for a given decision support system. In essence this is a non-automated aid for making voice recognition system decisions related to the design of an automated DSS.

A secondary objective is to provide users, developers, researchers, and all others concerned with voice recognition input with a current reference guide to voice recognition research. Keywords used in locating references are provided in Appendix B. This guide is included in Appendix C, an annotated bibliography of current VR literature, with subappendices that contain references to the annotated bibliography by functional areas of DSS. Appendix D furnishes the publishing source of all literature contained in the annotated bibliography and thus facilitates retrieval of hard-to-find articles.

A third objective of is to provide a current listing of all available voice recognition systems commercially available. This list is contained in Appendix E, along with information concerning compatibility with current computer systems for these voice systems. The voice recognition systems listed include a wide range of capabilities, and are useable on systems varying in size from mainframe computers to desk top microcomputers.

The overall goal of this study is to supply a useful guide for decisions concerning the implementation or use of voice input for decision support systems as well as for other computer applications.

## **E. SCOPE AND METHODOLOGY**

### **1. Scope**

This study primarily considers only current voice recognition literature, that is, books, articles, and reports that are less than five years old (published after 1 January 1983). A limited amount of older literature, determined especially pertinent and worthy of note, also is included.

Keywords used in searching the literature are listed in Appendix B. Words representing voice and speech-related topics not included in this study also are listed there. No experiments or case studies were conducted for this thesis.

### **2. Research Methodology**

Exhaustive research was conducted to identify all current and accessible voice recognition literature and voice recognition systems. This research was conducted using Naval Postgraduate School and University of California, Santa Cruz, resources and via locally accessible computer networks.

The universe of papers from which the database was drawn consists of all literature that contains keywords listed in Appendix B. Initially over 1000 references were located. These items were reviewed and filtered to determine those applicable to DSSs. As a result of a review process, over 230 articles were classified as applicable to DSSs and are included in the final database in the form of an annotated bibliography. In many cases this bibliography also contains excerpts, abstracts, or summaries of those articles related to voice recognition that are considered to be useful for users, developers, researchers, and others concerned with voice input to decision support systems.

## **II. DATA ANALYSIS**

### **A. BACKGROUND**

As fifth generation computer technology approaches, the use of "intelligent systems" will give increasing flexibility to the input devices of the future. The data collected for this study provides knowledge needed to pick the best method of human-computer interaction for the specific environments of a given DSS.

It has been proposed that speech is the human's highest capacity and most natural form of communications [Lombardo 84]. Therefore computer voice recognition would be the most natural way for humans to interface with machines. The problem preventing the widespread acceptance of VR seems to be that most people are simply not aware that VR exists or what it can really do for them.

This chapter discusses various research areas or categories of both voice recognition systems and DSSs. Data are placed into several categories in order to facilitate locating answers to specific problems and to aid in performing research related to a specific DSS application or environment. These categories were arrived at through an empirical process of reviewing the reports and noting logical trends in the literature. Each research area is related to an Appendix in this report containing references to articles germane to that area.

### **B. HUMAN FACTORS**

Categories of human factors included in this study are (1) stress, (2) multimodality, (3) user speaking experience level, (4) computer experience level, and (5) the size of the vocabulary. These topics are related to several human

factors areas: occupational, operational, psychological, physiological, and personal. [Yellen 83]

Human factors is discussed first because of its importance. No matter how fast the computer is, how efficient its speech recognition algorithm is, or how pretty its displays are, it will not be used effectively or efficiently unless human factors knowledge applicable to system implementation has been reviewed and incorporated.

Appendix C1, Section 1, contains a listing of material applicable to the area of human factors. Sections 2 thru 6 of that Appendix include references that are specific for each category within the scope of human factors.

### **1. Stress Related Factors**

Stress influences the sound wave frequency of an individual's speaking voice. Additionally, stressed speakers often appear to talk in longer bursts, with shorter pauses separating the bursts. Psychological stress also influences an individual's vocal production in other ways. However, there is no consensus in the literature concerning how stress can be analyzed to predict an outcome.

Stress may be either physiological, psychological, or a combination of both. Physiological stress is more clear cut than psychological, and refers to the result of human stresses such as heat, pressure, electric shock, and similar stimuli. Psychological stress comes from many sources and relates to an individual's ability to cope, adapt, or react to an unfamiliar, unfriendly, or threatening environment, or to the influence of that environment on the individual.

Psychological stress can be further subdivided into situational and self-induced stress. Situational stress is the influence of unfavorable environmental factors (excluding physical factors) on an individual. These factors are beyond the

individual's control and may include circumstances such as public speaking, deadlines, quotas, etc. Self-induced stress is the self-imposition of a condition or stimulus. These include self-imposed goals, deadlines, or performance requirements of any type with which an individual forces himself to function above a "comfortable" or "easy" level [French 83]. It is important to remember that in some cases it may not be possible to separate physical from psychological stimuli.

Research in the area of stress and voice recognition was found to be limited. References are listed in Section 2 of Appendix C1.

## **2. Multimodal Factors**

Voice recognition systems are unique in their ability to free the user's mind and eyes for carrying out visual tasks. A voice recognition system permits the user to view graphics, screens, and decision aids, to oversee personnel, or to read from a data source without having to remove the eyes in order to communicate with the computer.

Baker states in her keynote address to the First International Conference on Speech Technology:

Just as Darwin hypothesized that people developed spoken rather than gestural language so as to free up their hands and be able to communicate in the dark or out of sight, so speech recognition has seen its initial applications in "hands busy, eyes busy" applications. [Baker 84]

Voice recognition systems promise freedom from the distraction of interrupting the flow of work to recall codes and find keys. Voice recognition can free the operator from having to remain close to a specific physical installation, such as a video display terminal or keyboard. Additionally, the use of a wireless

microphone permits extensive mobility while talking to computers. French states that

Voice-input could enable the operator to continue the task at the terminal, and simultaneously manipulate a visual representation of the problem they are involved in, for others' benefit. This is a potential boom in the period of transition from a symbolic gestalt to an era of much more wide spread computer literacy. [French 83]

As cited by Yellen, with this increased mobility also come increased problems; breath noise can now create a serious problem [Yellen 83]. An individual who is involved in little or no physical movement while engaged in voice recognition can obtain very high recognition accuracy, but errors may be induced once the user begins to move. When using a close-talking, noise-concealing microphone, inhaling does not appear to cause problems; however, exhaling will produce signal levels comparable to speech levels.

The advantage of having ones hands, eyes, and mind free to perform other tasks could be the major contributing factor in the choice of voice recognition input to a computer application. This multimodal aspect of voice recognition enhances or compliments traditional tactile input methods rather than replacing them in total. A listing of literature related to the multimodal aspects of voice recognition is contained in Section 3 of Appendix C1.

### **3. Speaker's Experience Level**

Many studies have been done measuring the speaker's experience with voice recognition systems and the resulting quality of the output or task performance. The research in this area is referenced in Section 4 of Appendix C2.

Most studies generally agree that, regardless of the initial experience level of a speaker, novices quickly pick up voice recognition systems skills and that their

performance improves rapidly toward levels of experienced users. It is important to note that professional typing skills require a long learning period and diminish quickly with disuse. On the other hand, speaking is a natural output mode for the human and is practiced everyday by all. The user has only to restrict spoken utterances to those which the machines can recognize.

#### **4. Computer Experience Level**

It is a credit to the adaptability of humans that they can use today's software when so much of it still abounds with such non-memorable commands. Complex multiple command/control/shift keystrokes often are required which can only be recalled by constant and experienced users. Commands that require precise syntax, spacing, and order can be simplified by the use of voice commands. Once the utterance is recognized by the computer it is input correctly. Long commands or passwords which require accurate input and multiple keystrokes are easily mistyped, but can be input accurately with a voice recognition system.

The video display can provide directions for the next voice input through the use of menus or with a graphical representation. This can be of special value to both DSSs and Group DSSs, enabling rapid generation of "what if" brain storming or alternatives generation.

Section 5 of Appendix C1 provides a guide to publications that deal with a user's computer experience level. Many techniques are listed in these articles which enable better performance, given a specific experience level.

#### **5. Vocabulary Factors**

The vocabulary selected for a voice recognition system affects the speed and accuracy of the system in many ways. The selection and structure of the vocabulary is extremely important to the success of the system. The vocabulary

should be as natural as possible, while avoiding conflicting, confusing, or similar sounding utterances.

Most current voice recognition systems perform well with small vocabularies. When the size of these vocabularies gets large (greater than 1000 utterances) the probability of error increases, along with the processing time. The possibility of confusion between words increases with vocabulary size also, as does the probability that similar sounding words have been included. Better speech recognition systems usually have recognition algorithms designed to reject rather than guess at questionable or similar words.

Humans have a low tolerance level for waiting for machines and for machines that make errors; studies show that humans tend to abandon systems that perform in this manner. With very large vocabulary sets, the amount of data to be processed for each recognition is intolerably large unless coding is optimal and optimized comparisons are used. Accuracy is increased and recognition time decreased by using vocabulary subsets. A given subset usually is entered by saying the subset's name or title (also called the node word). Once in this subset or node, the system will search and recognize only the words included in this subset. This increases both speed and accuracy, and allows for different output for a given input.

For example, a subset of numbers may be entered with the node word "number". Only words representing those numbers contained within the node will be recognized (along with node words which exit the subset). This allows the use of homonyms (such as "two" and "to") without confusion. When in the subset of "numbers", the utterance "to" or "two" will produce an output of "2". When in

other systems the utterance "to" or "two" will produce the output string of "to" (or any other preprogrammed output desired).

The selected vocabulary can also be used to overcome problems related to cumbersome program commands or other often-forgotten commands through allowing for various input utterances to result in the same output string. For example, each computer network has a specific command to log off or check out of the system. These usually differ from system to system, and it may be difficult to remember which is required for each system. Programming three or four different utterances that produce the same correct output command will alleviate this problem (e.g., "log out", "log off", "check out", and "bye bye" might all correspond to the output string "LOGOFF ^M"; saying any of them produces the desired result).

Literature related to the area of speech recognition system vocabularies is referenced in Section 6 of Appendix C1.

### **C. ENVIRONMENTAL FACTORS**

The environment in which a system will be used can play a decisive role in the choice of the input device and the voice recognition system to be used. In a United Nations command center that is dark, noisy, and filled with people from many nations with varied languages and customs, typing commands to a computer in one language in a fixed syntax is not practical. A well-implemented voice recognition system can do this job faster and without the mistakes normally associated with human translators. This "Tower of Babel" in which one can communicate as if with one tongue can be implemented with current technology through proper design.

References to environment-related studies and research are found in Section 1 of Appendix C2. Subsets of these references, related to specific environmental factors, are provided in Sections 2 through 6 of Appendix C2.

### **1. Multilingual Factors**

The UN example may be the extreme, but in this world of instant worldwide telecommunications, international businesses, and melting pot nations, computers frequently must interface with people who speak different languages. Voice recognition systems are unconcerned with what language is spoken. They operate by matching the pattern of a given voice input (utterance) with a known pattern and then outputting some predesignated command string, therefore acting somewhat like a translator. For example, three languages may be spoken in an office (English, Spanish, Hindi). The computer software requires input in English. It is impractical to teach all the personnel both English and the commands required to operate the computer. A voice recognition system could be installed that "understands" utterances in all three languages and outputs the English commands that the software requires.

Research and other literature related to voice recognition with multilingual environments is found in Section 2 of Appendix C2.

### **2. Multicultural Factors**

Multicultural factors arise when different people have different ideas, styles, or ways of doing things. All computer operating systems perform similar functions, but there are subtle differences in the way commands are activated. For example, for a simple file transfer, the UNIX operating system uses a specific syntax that is completely different from that used by an IBM operating system.

Switching between MS-DOS, Z-DOS, Apple DOS, and the Macintosh operating systems usually will require the user to look up the desired commands.

Voice recognition systems can ease these difficulties by doing the lookup for the user: the same phrase, "save and quit", can be programmed to produce the same result on all systems. Voice recognition can also help equalize the varied experience, training, and typing skills of workers or executives exposed to new systems or new situations.

Literature sources related to multicultural factors are referenced in Section 3 of Appendix C2.

### **3. Command and Control Environments**

Military establishments have done much work toward application of voice recognition systems in the command and control environment. The result of this work has been the acceptance and implementation of operational voice recognition systems in both strategic and tactical command and control environments. Most of this research can also benefit civilian business and industry applications. A listing of current research relating the areas of voice recognition systems and command and control is provided in Section 4 of Appendix C2.

### **4. High Noise Environments**

Voice recognition systems have been used effectively in quiet office environments and also in noisy industrial assembly areas (noise levels in excess of 100 db). Although voice recognition equipment manufacturers have endeavored to make their equipment work equally well in both environments, there are some locations where it is still too noisy for voice recognition systems to operate unaided. In such environments the use of a soundproof booth or a mask (such as a noise-reducing stenographer's mask) can help; external noise is diminished and effective voice recognition can take place.

Most researchers agree that, when using speaker dependent systems, "training" voice samples should be collected in the environment in which they will be used. This is especially true with noisy environments.

Another method to improve voice recognition in a noisy environment is to use a speech enhancement algorithm. This is a software technique used to clean up the speech pattern before it enters the recognition device. A noise concealing microphone (like those that have been used in aircraft for years) also can be used. This microphone samples the environmental background noise and aids in canceling out this background noise prior to its being sent to the recognizer.

When noise is a consideration in the environment, a close look at research in this area is critical. Even for quiet office environments, an understanding of noise as it relates to voice recognition is recommended. Most mechanical things make noise, some at frequencies that the human cannot hear or chooses to ignore due to familiarity. The noise of a car, airplane, copy machine, or elevator during training or execution of voice recognition commands can result in puzzling problems. Noise-related articles and research are listed in Section 5 of Appendix C2.

## **5. Low-Light Environments**

Low-light environments include both dimly lit control rooms and completely darkened auditoriums. In these environments, lighting can interfere with the performance of the operators' primary mission. The cockpit of an aircraft and the bridge of a ship are specific environments where good night vision is paramount. During daylight, normal manual input devices are adequate. At night,

a light source can have life-threatening consequences. A voice recognition system allows for sightless input of computer commands plus mobility.

Voice recognition systems can be used to control the lights in a room. A more complex use would involve a microprocessor voice recognition system in a welders helmet that controls the welding unit, turning it on and off and also controlling the voltages or gas flow remotely.

References relating voice recognition systems to low-light environments are listed in Section 6 of Appendix C2.

#### **D. SITUATIONAL FACTORS**

Situational factors covered in this study include (1) system use by a group, (2) use by an individual, and (3) use by handicapped persons. Appendix C3, Section 1, provides a complete list of voice recognition systems references related to such situational factors.

##### **1. Multiuser or Group Usage**

A multiuser system is a single system that is used by many people but only one at a time. Group usage is the use of a system by many people during the same time period. Both multiuser and group usage have similar problems and characteristics and have thus been grouped together in this study.

Multiuser-oriented systems can be either speaker dependent or independent. They can use either continuous or discrete speech recognition algorithms. These terms are defined as follows.

- **Speaker Dependent Systems:** require adaptation (or "training") of the voice recognition system to the speech characteristics of each user in order to achieve recognition.
- **Speaker Independent Systems:** recognize speech regardless of the speaker, and without system training in recognition of individual speech characteristics of users.

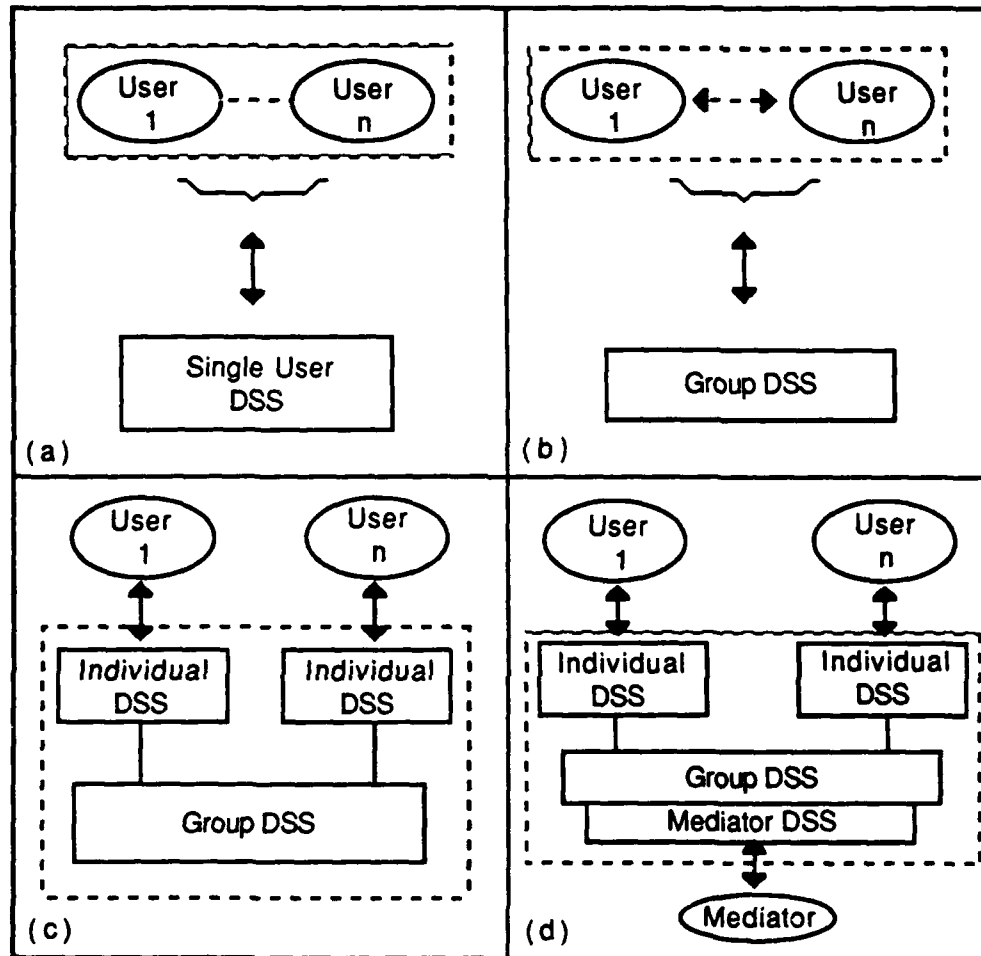
- **Continuous Speech Recognition:** the process of extracting information from strings of words even though the words run together as in natural speech. [Yeller 83]
- **Discrete (Isolated) Speech Recognition:** the process of transforming discrete utterances (those with a significant pause between utterances) into computer-recognized speech or text.

Although speaker independent, continuous systems are better suited and require less training for multiple users, other combinations should not be ruled out, as they offer some advantages in specific circumstances. If the group situation also involves environmental factors (such as in a multilingual, high noise command post), the difficulty of selecting a system is compounded. Speed or vocabulary size or robustness may dictate that a speaker dependent, discrete speech system be used, even though system training time is higher and sampling is required.

Implementing voice recognition input to a Group Decision Support System (GDSS) is difficult since there are four basic GDSS typologies, each presenting its own unique problems. Figure 2.1 shows these four typologies. [Bui 87].

Figure 2.1 (a) shows a bilateral relationship between a single-user-oriented DSS and a group of users, the later being considered as a whole. The purpose of such a DSS is in essence the same as a single-user DSS. [BUI 87] In this situation a voice recognition system that is robust enough to fit the needs of the group is required. If the size of the group is small and its composition constant, a discrete, speaker dependent system (requiring system training by the users) is practical. Otherwise, a speaker independent, continuous speech system would be most appropriate. With a varying group, the cost and time required to sample and train each user and the constraints on vocabulary size could be prohibitive. Figure

2.1 (b) extends the previous typology to include a GDSS, and has the same associated problems.



**Figure 2.1. Typologies of Group Decision Support Systems [Bui 87]**

Figures 2.1 (c) and (d) illustrate a multilateral relationship between a member of a group (via a network of individual DSSs) and a GDSS. This typology allows the customization of individual DSSs to suit the needs of users. Currently the cost of a GDSS of this nature is too great for most user organizations;

centralized or off-site facilities (leased from or provided by a vendor), used by many diverse groups, are the norm. Requirements for minimal training time and the variability of users usually necessitate the use of a robust, speaker independent, continuous speech system.

There is no perfect solution to all situations. Each installation should be evaluated on its own merit by well-informed analysts. Section 2 of Appendix C3 provides references to research in this area.

## **2. Individual Usage**

Voice recognition for individual usage offers the greatest possible number of options. Many factors can be considered when optimizing the system, which can be speaker dependent or independent, and use continuous or discrete recognizers.

Voice recognition systems can also be used to augment other input devices. They can be used simultaneously with keyboards and pointing devices. In the fields of desktop publishing, graphics manipulation, or computer-aided design, the task of entering text is secondary to the drawing of shapes or manipulation of objects on a screen. A voice recognition system or a "talkwriter" can be used to perform a text entry task and thus not break the flow of carrying out the primary task.

The most important constraint when designing a system is the time and effort required for training. References relating voice recognition systems to individual users are provided in Section 3 of Appendix C3.

## **3. Handicap Situations**

A physical handicap does not impair a person's mental ability or ability to produce. Just as a person with an amputated leg is given a prosthetic device to allow

mobility, a voice recognition system can be used as a prosthesis that can compensate for some physical handicaps. Much work has been done in this area to bring independence, mobility, and productivity to the handicapped. Voice recognition systems not only can be used by the handicapped to operate computers, but they also can be used to control or manipulate other mechanical devices.

Wheelchairs, prosthetic devices, communication devices, environmental controls, and many other systems may be controlled via the voice. The highly individual nature of designing a voice recognition system for the handicapped can result in the use of small, lightweight, power efficient, portable units, fine-tuned for the user and his or her needs.

Research related to the handicapped and voice recognition is located in Section 4 of Appendix C3. Much of this research is equally applicable for use with non-handicapped individuals.

## **E. QUANTITATIVE FACTORS**

Some of the benefits or advantages of computer voice recognition systems are subjective (user convenience or preference). Other aspects are undeniably quantitative. These include response and task time, accuracy, speed of entry, ease of use, and user productivity. References that evaluate or discuss these quantitative measures are found in Section 1 of Appendix C4.

### **1. Time**

Time savings can be measured in many ways. Baker cites data from experiments that show communications via typewriter or hand-writing cannot even approach speech, in terms of time or task efficiency [Baker 84]. Time saving, in terms of hours required to train the user on the system or in actual hours saved by the use of voice recognition, are significant, especially in common environments.

As voice recognition systems become commonplace and familiar, the time saved in training personnel is expected to increase.

References in the area of response and task time, related to voice recognition systems, are included in Section 2 of Appendix C4.

## **2. Accuracy**

One of the selling points of voice recognition systems is the accuracy of task performance. Once an utterance is correctly "understood", the system will produce a precise and correct output. However, two types of errors may occur: rejection and misrecognition. Rejection is the inability of a recognizer to classify a utterance correctly. Misrecognition happens when a recognizer classifies an utterance as something other than what was spoken. Since misrecognition is potentially more serious, most good recognizers are designed to reject rather than guess at marginal pattern matches.

Experiments have shown accuracy rates ranging from a high of 99.8 percent to lows in the range of 88.6 percent. The accuracy required of a system depends on the criticality of its application and the consequences of errors in the entered data.

Research has shown that 183 percent more errors occur during manual data manipulation (typing) than when a voice recognition system is used [Yellen 83]. Common typing errors such as the transposition of numbers or letters are almost eliminated with voice recognition. Correct entry of numbers is especially important since automated spelling and grammar checkers can catch most letter transpositions.

Voice recognition accuracy can be improved in many ways, as covered in the Training Factors Section of this Chapter. Briefly stated, recognition accuracy

depends primarily on how the equipment is trained and on the experience level of the speaker. Computer experience, time of week, accent, vital capacity and rate of air flow, speaker cooperativeness, and anxiety all affect accuracy to a lesser extent. References providing other data concerning accuracy are included in Section 3 of Appendix C4.

### **3. Speed of Entry**

Most researchers agree that speech input is faster than keyboard input. Most individuals can speak twice as fast as the average typist can type. With a greater number of nontypists gaining access to computers, faster input modes are needed. The Macintosh personal computer from Apple uses a pointing device, pull-down windows, and other enhancements (which augment the keyboard) to produce a more natural interface. Experiments evaluating the Macintosh's pull-down windows in comparison with continuous voice recognition input demonstrated a distinct advantage in using continuous speech over the pull-down window technology of the Macintosh. [Sweeney 86]

In other research, after only three hours of training, subjects were 17 percent faster using voice entry than typing [Yellen 83].

References concerning task completion speed are listed in Section 4 of Appendix C4.

### **4. Ease of Use**

Various studies have been carried out that demonstrate that speech input is easy to learn and easy to use. Users also develop a preference for speech input in time. References to these studies are located in Section 5 of Appendix C4.

## **5. Productivity**

Computers excel in performing repetitious, time consuming, and boring tasks; humans do not. Thus productivity will be increased when such tasks can easily be turned over to a computer, especially if voice commands can be used to initiate the desired operations.

One device that uses a voice system to increase productivity is the "talkwriter" or voice dictator. As the user speaks, words are recognized, entered into a file, and displayed on a screen. When more than one interpretation is possible, the system may provide a list of its best guesses; the user selects one. Better-developed models have very large vocabularies and automatic sentence punctuation.

References relating voice recognition systems and productivity are listed in Section 6 of Appendix C4.

## **F. TRAINING FACTORS**

Training of the user and the voice recognition system is one of the most important considerations in the effective implementation of systems. Methods of training depend on the type of voice system being implemented: speaker dependent or independent systems, and continuous or discrete speech systems. Certain training techniques have been developed that can improve recognition accuracy and reduce errors. The complete list of references to training is found in Section 1 of Appendix C5.

### **1. Speaker Dependent Systems**

Speaker dependent systems require that samples of the potential user's voice be placed in computer memory. The system basically is tuned for each user's

voice. Usually these systems work better than a speaker independent systems because the dependent system contains samples of the actual user's voice. [Poock 83]

Speaker dependent systems are well suited to situations where the same users perform the same job day in and day out. However, consistency is also a key element in successful recognition accuracy: a speaker may talk quite differently when training the machine than during operational use. Whenever possible training should be conducted in the same environment as the equipment will be operated in, to minimize variability that may affect recognition accuracy. Other factors that affect training and recognition accuracy are age, physical condition, fatigue, stress (emotional or physical), time of week, breath noise, microphone placement, familiarity, illness, peer pressure, workload, and external noise changes. When changes must occur, a new "training" session will usually retune the system and restore accuracy.

Vocabulary size also affects recognition accuracy. As familiarity with a voice recognition system increases and the vocabulary is expanded, there will be more utterances that sound alike or similar to the recognizer; the system may start to reject words as unrecognized that formally were accepted. To improve recognition of troublesome words, using duplicate words trained separately sometimes will increase performance of that particular word.

References to current research related to speaker dependent systems are listed in Section 2 of Appendix C5.

## **2. Speaker Independent Systems**

A speaker independent speech system contains algorithms that can handle many different voices and dialects. The system is designed to recognize the voice of anyone who uses it, and thus is useful when many people are expected to operate

it daily. Unlike speaker dependent systems, speaker independent systems do not require samples of a given user's voice. As a result, speaker independent systems do not usually perform as well as speaker dependent systems that are tuned to a specific user's vocal characteristics.

Vocabulary size and structure play an especially important part in voice recognition accuracy with speaker independent systems. As the size of the vocabulary increases, the possibility of confusion between words also increases since there is a greater chance that there will be similar sounding words.

References related to speaker independent voice recognition systems are listed in Section 3 of Appendix C5.

### **3. Continuous Speech Recognition**

Continuous or connected speech recognition systems can extract information from strings of words even though the words run together as in natural speech. Continuous speech is much more natural for humans to use than is discrete speech, which requires pauses between utterances. During the 1970s, most voice recognition systems used discrete speech. More recently, many accurate and inexpensive connected speech systems have been developed.

Continuous speech systems can either be speaker dependent or independent. They usually involve larger vocabularies and require more powerful computers to run them. "Talkwriter" devices, discussed earlier, are connected speech systems with very large vocabularies

A new approach to continuous recognition moves away from matching scheme algorithms to more flexible "phonetic" recognition schemes. Phonemes, the basic units of all speech, are the basis for phonetic recognition. This type of

system is trained using words incorporating all combinations of phonemes. The formulation of new words from these phonemes then is possible.

References relating to continuous speech recognition systems are listed in Section 4 of Appendix C5.

#### **4. Discrete Speech Recognition**

Discrete or isolated speech recognition is the process of transforming discrete utterances into computer-recognized commands or text. Discrete speech contains a significant pause between utterances. A discrete speech recognizer must be able to detect a pause or low energy gap in order to function. Humans, however, sometimes find it difficult to speak with isolated words or broken phrases; hence discrete speech is not the most natural or desirable form of voice recognition.

Until recently, almost all commercial applications of voice recognition technology have been discrete voice recognition systems. Discrete systems still offer some advantages over continuous recognition systems in the areas of speed, accuracy, and especially cost. An extensive listing of currently available commercial voice recognition systems is contained in Appendix E. Usually, unless a system is advertised as being continuous or connected, it is understood to be of the discrete variety. References contained in Section 5 of Appendix C5 provide additional information about discrete speech recognition.

#### **5. Recognition Accuracy**

Training plays perhaps the most significant role in recognition accuracy. Problems often arise as a result of changes, either with the user or within the environment. A computer usually is much more sensitive to these changes than is the human. An impartial observer trained to detect subtle changes and who understands the mechanics of the system may be needed for trouble shooting and

system repair. For speaker dependent systems, a simple retraining session may restore accuracy. The use of vocabulary nodes or subsets can increase both speed and accuracy (see the Vocabulary Factors Section). Duplicate words that result in the same output string may minimize rejection problems. Increasing the word recognition threshold may cause a higher rejection rate but can minimize misrecognition.

Most systems come from the manufacturer adjusted to a optimal level; making changes may only decrease performance. The operations manual gives the best guidance to how this manipulation of the parameters of recognition can improve or detract from recognition. Publications listed in Section 6 of Appendix C5 provide additional information on recognition accuracy.

## **G. HOST COMPUTER FACTORS**

Voice recognition systems have been used successfully on all types and sizes of computers. Appendix E lists current voice recognition systems and describes the host computers that each is compatible with. Voice recognition has also been used in aircraft and spacecraft control; telephones; robot control; in teaching people how to speak; and by the handicapped to control body limbs, home appliances, wheelchairs, and other conveyances.

As voice recognition systems mature they will become smaller, cheaper, have larger vocabularies, and be more robust. As a result of this they are expected to find their way into more computer applications and be involved in more aspects of human endeavor. Section 1 of Appendix C6 provides a complete list of references concerning host computer applications for voice recognition.

## **1. Microcomputers**

Voice recognition systems can provide input to microcomputers via many different configurations, both internal or external. External "voice boxes" are perhaps the easiest to install and maintain. They are self-contained units that may have an interchangeable storage medium device that allows for swapping or installing vocabularies or software. These storage devices can take the form of floppy disks, tape cartridges, integrated circuit chip cartridges, compact optical disks, and other types of magnetic and optical storage devices.

A replacement keyboard is one simple and inexpensive way to install a voice recognition system. These systems require no additional space or alterations to the microcomputer, they draw their power from the normal keyboard connection, and have ports for the voice recognition microphone and related switches built into the keyboard. Much of the unique voice recognition circuitry that usually is installed on an internal microcomputer board is in the keyboard. The disk storage device of the computer is used for its vocabulary and other software. Programming this type of system is easy as it mimics the normal keyboard keystroke inputs. Other software is unaffected by the system and is unaware that the user is entering commands via voice rather than by manual keystrokes.

Another implementation is through the use of an internal plug-in circuit card. This card operates in a manner similar to that of the keyboard, with the microphone and switches plugging into the card. These cards may incorporate other functions such as a modem or speech synthesis unit.

Some voice systems are actually incorporated into the basic design of the microcomputer and are internal and omnipresent to its operation. Specific

information on these and other microcomputer voice systems are referenced in Section 2 of Appendix C6.

## **2. Mainframes**

Mainframe computers may be accessed by the same types of methods as those noted for microcomputers. Links from microcomputers used either as dumb or intelligent terminals also may be used for access.

Because of the powerful processors and large, fast-access storage devices associated with mainframe computers, much research has been done with voice recognition related to large computers. Research literature concerning mainframe computers and other large computer applications of voice recognition systems is listed in Section 3 of Appendix C6.

## **3. Networks**

Computer networks and voice recognition systems come as a natural extension of microcomputer and mainframe application of voice recognition. Separate vocabulary nodes or specialized vocabularies may be used when accessing different networks. Passwords and entry procedures can be incorporated into the output strings, removing much of the drudgery related to moving through a network. The implementation of speech recognition also allows the use of voice verification as an automatic entry and access device.

Two of the largest networks used today are the telephone network and the automatic teller machine networks. Voice recognition systems have been proposed for these networks, and development efforts are underway. References related to voice recognition and networks are contained in Section 4 of Appendix C6.

#### **4. Types of Entry Required**

Data entry requirements vary from application to application. Voice input can be used to collect data, as in inventory control or quality control and assurance situations. Voice input can be used to input data or information into a computer, such as in order processing, or to manipulate data, as in automatic message preparation. Voice can be used to convert speech to text, as in the "talkwriter" or automatic dictation machines. Voice can verify data that has been entered by others or that has been mechanically or automatically entered via some other input device. Voice can be used to control industrial processes, machines, and robots.

Each of these applications requires a different type of system to make it work optimally. References related to data entry systems are provided in Section 5 of Appendix C6.

#### **H. EXPERIMENTS AND RESEARCH**

A vast amount of research has been conducted in both broad and specific areas of voice recognition. Section 1 of Appendix C7 contains references to this research. This research is further divided into logical groupings, to allow focused study. Section 2 of this Appendix covers research in the area of artificial intelligence. Section 3 looks at future research, that is, those areas in which new trends are developing or towards which research is predicted to move. Section 4 deals with present research, covering work done in the last five years. Section 5 includes literature related to research conducted prior to 1 January 1983. Many experiments and case studies have been conducted. Section 6 is devoted to these.

A special area of interest has evolved relating the field of voice recognition to the area of natural language interfaces. Dobney states that natural language

interfaces and speech recognition are fifth generation concepts. A natural language interface allows a user to express his or her request in English. Certain difficulties arise when using naturally spoken English. The problem is related to the use of homonyms, such as "I heard the song" and "I saw a herd of buffalo". A related difficulty results when phrases sound similar, such as "I scream" and "ice cream". [Dobney 87] The human mind has developed ways to sort out these problems; humans understand the context of what is being said, and are sensitive to shifts in context. Dobney presents some interface complexities which natural language processing must address and resolve. Some of these are listed here to demonstrate the scope of this problem.

- Time flies like an arrow  
Fruit flies like a banana.
- You wouldn't recognize Mary now. She's grown another foot.
- Can anyone walk over Niagara Falls on a tightrope?
- A sandwich is better than nothing.  
Nothing is better than a good square meal.  
Therefore a sandwich is better than a good square meal. [Dobney 87]

The challenge will be to develop machines that will do what we mean, and not necessarily what we say. Literature documenting research dealing with natural language interfaces is found in Section 7 of Appendix C7.

### **III. RESULTS AND CONCLUSIONS**

#### **A. RESULTS**

The primary objective of this thesis is to provide a single source of reference to enable the selection of an appropriate voice recognition system implementation for a given DSS or other computer application. Chapter II, Data Analysis, fulfills this objective by providing both a broad overview of voice recognition systems and their characteristics and a close-up view of specific categories within voice recognition.

The second objective is to provide a reference guide to current voice recognition literature and research. Appendix C is such a guide. It contains an annotated bibliography and has subappendices that directly link this bibliography to specific areas of research that are discussed in Chapter II. An additional result of this study is Appendix D, a complete index of all publishers mentioned in the bibliography, which should facilitate retrieval of articles that might be difficult to locate.

The third objective is to provide a current listing of all commercially available voice recognition systems. This listing is contained in Appendix E, and gives each manufacturer's name, address and phone number. The various types of voice input devices manufactured, their intended use, and their compatibility with current computer systems also are provided there.

The overall goal of this study is to provide a useful guide to help in the decision making process concerning the implementation or the use of voice recognition systems. Information in this study can be used both as an introduction to voice

recognition systems and as a reference source to answer questions on specific topics. The direct linking of specific topics to a grouping of articles dealing with this topic allows use of this study as a ready reference source.

## **B. CONCLUSIONS**

As discussed in Chapter I, the dialog component of decision support systems may be the weak link when implementing a DSS. By using voice recognition systems to optimize this dialog component, the overall DSS will benefit.

As noted in the Voice Recognition Systems Section of Chapter I, voice recognition, as well as other fifth generation concepts is expected to be critical for the future of most computer applications.

Research listed in the Human Factors Section of Chapter II has shown that stress may result from a fear of new technology. Fear of new technology is not a recent phenomenon. This fear of voice recognition systems often is a result of the user not being previously introduced to such systems. Fear also can result when the user is unaware of what voice recognition can actually do (and cannot do).

Considering the importance of voice recognition and its proven value to human productivity, the volume of recent research is not increasing proportionally to its perceived importance. This is indicated by the amount of literature referenced throughout Chapter II. The volume of publications has not increased in recent years at the rate of studies done in earlier years.

#### IV. RECOMMENDATIONS

It is recommended that designers and users of DSSs investigate voice recognition systems as a means of optimizing the dialog component of DSSs. As noted by Ralph Sprague, describing the future of Decision Support Systems, "Dialog will profit significantly from the inclusion of natural language processing techniques and voice recognition" [Sprague 87].

As the reality of fifth generation computer technology approaches, the use of "intelligent systems" such as natural language processing and voice recognition systems will allow for both flexible and natural input. Although no one input method is perfect or even appropriate for all uses, voice systems show promise for wider applications than presently are being implemented.

Widespread acceptance of computer voice recognition can be encouraged by proper training and orientation of potential users of such systems. A good training and education program in the use and benefits of voice recognition will help smooth the path for voice recognition implementation.

More research is needed in all areas of voice recognition. Only through continued research and experimentation can voice recognition systems develop and improve. The perceived recent lull in voice recognition research may in part be due to normal delays in the publishing process or to recent cutbacks of research funds. However, since the demand for better input methods continues, research must also continue.

It is hoped that this study can help guide and inspire the use of voice recognition systems for decision support systems and other computer implementations. A tool has been provided that can enable quick reference to

literature related to specific areas of concern and research within the domain of computer voice recognition. Continued education and enlightenment should result in progress and greater acceptance of these systems.

## APPENDIX A GLOSSARY OF TERMS

Group Decision Support System (GDSS): a computer-based system that aims at supporting collective problem solving. A collective decision-making process can be viewed as a problem solving situation in which there are two or more persons, (1) each of whom is characterized by his or her own perceptions, attitudes, motivations, and personality, (2) who recognize the existence of a common problem, and (3) who attempt to reach a collective decision. [Bui 86]

Decision Support System (DSS): the application of available and suitable computer-based technology to help improve the effectiveness of managed decision making in semi-structured tasks. [Keen 78]

Voice Recognition (VR): the ability of a computer or device to recognize spoken words correctly and translate those sounds into a predetermined output string to a computer; also referred to as automatic speech recognition (ASR) [LeFever 87]

Continuous Speech Recognition: the process of extracting information from strings of words even though the words run together as in natural speech. [Yeller 83]

Discrete (Isolated) Speech Recognition: the process of transforming discrete utterances (those with a significant pause between utterances) into computer-recognized speech or text.

Utterance (Word): may be a single mono- or polysyllabic word (e.g., select) or a combination of mono- or polysyllabic words joined into a phrase (e.g., select-the-first-choice).

**Rejection:** the inability of a recognizer to classify an utterance correctly.

[Yellen 83]

**Misrecognition:** classification by a recognizer of an utterance as something other than what was spoken.

**Speaker Dependent Systems:** require adaptation (or "training") of the voice recognition system to the speech characteristics of each user in order to achieve recognition.

**Speaker Independent Systems:** recognize speech regardless of the speaker, and without system training in recognition of individual speech characteristics of users.

## **APPENDIX B    KEYWORDS**

### **KEYWORDS**

Automatic Speech Recognition (ASR)	Speech Input/Output
Automatic Word Recognition (AWR)	Speech Recognition
Continuous Recognizer	Speech Technology
Decision Support System (DSS)	Speech Understanding
Group Decision Support System (GDSS)	Talkwriter
Human Computer Interface	Voice Input
Individual Decision Support System (IDSS)	Voice Input/Output
Man Machine Voice Interface	Voice Processing
Natural Language Voice Input	Voice Recognition
Natural Language Accessed	Voice Recognizer
Speech Entry	Voice Vocabulary
Speech Input	

### **TOPICS NOT INCLUDED IN THIS STUDY**

Speech Output	Voice Response
Speech Synthesis	Voice Synthesis
Voice Identification	Voice Verification

## APPENDIX C ANNOTATED BIBLIOGRAPHY

[Allen 83] Allen, J., *Recognizing Intentions from Natural Language Utterances*, pp. 107-166, MIT Press, 1983. ISBN 0-262-02183-8.

[Anatharaman 86] Anatharaman, T., and Bisian, R. A., "Hardware Accelerator for Speech Recognition Algorithms", *Computer Architectural News*, pp. 216-N223\*, June 1986.

[Andrews 84] Andrews, Harold L., "Speech Processing", *Computer*, v. 17, pp. 315-324, October 1984.

Argues whereas machines that can reach the communication skills of HAL, the computer from 2001, are still remote, viable and cost effective speech products can be realized. 25 references.

[Anisworth 84] Anisworth, W., and Foster, H., "The Use of Dynamic Frequency Warping in a Speaker-Independent Vowel Classifier", *New Systems and Architectures for Automatic Speech Recognition and Synthesis*, Springer-Verlag New York, Inc., pp. 389-403, 1984. ISBN 0-387-15177-X.

[Armstrong 80] Armstrong, J. W., *The Effects of Concurrent Motor Tasking on Performance of a Voice Recognition System*, Master's Thesis, Naval Postgraduate School, Monterey, California, September 1980. AD A7147.

This research investigated the effects of concurrent operator motor loading on performance of a voice recognition system comprised of a human operator and a discrete utterance voice recognition system. Increased concurrent operator motor loading (with respect to that experienced during training of the voice recognition system) was found to degrade system performance. Operator motor loading was manipulated using a rotary pursuit tracker. A special vocabulary was used to ensure a baseline recognition error rate to facilitate detection of factors influencing system performance. The results using the special vocabulary also indicated the

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\* Page references listed in the format "pp. 216-N223" indicate that the information is not contiguous within the noted pages.

performance degradations that a real world operator may encounter when using different phrases that are similar to one another in sound.

- [Armstrong 81] Armstrong, J. W., and Pooock, G. K., "Effect of Task Duration on Voice Recognition System Performance", *National Technology of Informational Service*, September 1981. AD A107442.

- [Baker 84] Baker, Janet, "The Freedom of Speech", *Proceedings of the 1st International Conference of Speech Technology*, pp. 1-11, October 1984.

Keynote address, 1st International Conference of Speech Technology. This essay explores the progress of speech, past, present, and future, and the creative challenges now spinning about us.

- [Bakst 87] Bakst, Shelley, "Voice Recognition Systems: Are They Ready to Listen?", *Office Systems*, v. 4, pp. 70+, April 1987.

Discusses voice recognition systems pointing out that the ultimate "talkwriter" is still unavailable but rapid technology enhancements to these products require that office-system planners begin to take the technology seriously and start determining possible applications in their organizations.

- [Banatre 83] Banatre, J. P., Frison, P., and Quinton, P., "Network for the Detection of Words in Continuous Speech", *Acta Informatica*, pp. 431-448, January 1983.

- [Berman 84] Berman, J. V. F., "Speech Technology in a High Workload Environment", *Proceedings of the 1st International Conference of Speech Technology*, p. 69, October 1984.

Speech technology can provide a man-computer interface which is qualitatively different from conventional systems. While speech constitutes a natural form of interpersonal communication, difficulties may occur when speech is used for a different purpose, due to the limitations of human information processing capabilities. These capabilities will be discussed and laboratory experiments described which demonstrate some underlying principles by which aspects of the task structure must be constrained, especially in a high-workload environment. These considerations should help system designers to maximize the potential benefits offered by speech technology, and minimize its impact on such diverse factors as multiple task performance and the limitations of human working memory.

- [Betterton 83] Betterton, Andrew, "Voice Recognition Moves Out of the Labs," *Computer Data*, v. 8, p. 6, October 1983.

Explains some of the advances that have been made in the voice recognition field but points out that the technology is still in its very early stages.

- [Bierfert 85] Bierfert, H., and Von Winfield, V., "Automatic Speech Recognition: From Theory to Practice", *Sprache und Information*, p. 340, 1985. ISBN 3484319119.

- [Biermann 84] Biermann, Alan W., Gilbert, Kermit C., and Fineman, Linda S., "Introducing Vips: A Voice-Interactive Processing System for Document Management", *National Computer Conference Proceedings*, pp. 661-666, 1984.

Describes a voice-interactive processing system that enables a user to display office-related data on a screen and manipulate it through a combination of voice and touch commands. 21 references.

- [Biermann 85-1] Biermann, A. W., Fineman, L., and Gilbert, K. C., "An Imperative Sentence Processor for Voice Interactive Office Applications", *ACM Transaction on Office Information Systems*, v. 3, pp. 321-346, October 1985.

An interactive sentence processor that enables a user to manipulate text with connected speech and touch-graphics input is described. The processor includes capabilities to follow dialogue focus, execute a variety of imperative commands, and handle nested noun groups, pronouns, and other phenomena. A micro model of the system, giving enough structure to enable the reader to observe internal mechanisms in considerable detail, is included. This processor is designed to be transported to a number of other office automation domains such as calender management, message-passing, and desk calculation. Various examples and statistics related to its behavior in the text manipulation applications are given. The system has been implemented in PASCAL and can run on any machine that supports this language.

- [Biermann 85-2] Biermann, A., and others, "Natural Language With Discrete Speech as a Mode for Human-to-Machine", *Journal of Communications of the ACM*, v. 28, n. 6, pp. 628-635, June 1985.

A voice interaction natural language system which allows users to solve problems with spoken English commands has been constructed. The system utilizes a commercially available discrete speech recognition which requires that each word be followed by approximately a 300 millisecond pause. In a test of the system, subjects were able to learn its use after about two hours of training. The system correctly processed about 77 percent of the over 6000

input sentences spoken in problem-solving sessions. Subjects spoke at the rate of about three sentences per minute and were able to effectively use the system to complete the given tasks. Subjects found the system relatively easy to learn and use, and gave a generally positive report of their experience.

- [Bisiani 84] Bisiani, R., "Computer Systems for High-Performance Speech Recognition", *New Systems and Architectures for Automatic Speech Recognition and Synthesis*, Springer-Verlag New York, Inc. pp. 169-190, July 1984. ISBN 0-387-15177-X.

- [Blunden 80] National Technical Information Service AD A-82/02, *The Impact of Speech Input and Recognition Systems on the Communications Industry*, by Brian Blunden, and others, p. 100, May 1980. Paper Industry Research Association.

Investigates the impact of speech recognition on the communications industries and in particular its use as a speech input device to the printing industry. The study is based on interviews with senior executives and visits to research centers in various countries along with a literature survey.

- [Bridle 83] Bridle, J. S., Brown, M. D., and Chamberlain, R. M., "Continuous Connected Word Recognition Using Whole Word Templates", *Radio and Electronic Engineering*, v. 53, pp. 167-175, April 1983.

Machines that recognize isolated words from a small, predefined vocabulary have been commercially available for many years. The whole word pattern-matching principles used in these machines are described, and it is shown how these principles can be extended to deal with continuously spoken sequences of words. Details are given of the resulting connected word recognition algorithm which has already been implemented in the real-time hardware, which will be used to explore the full potential and limitations of the method in many different applications.

- [Bridle 84] Bridle, J. S., "Challenges and Opportunities in Techniques for Speech Pattern Processing", *Proceedings of the 1st International Conference of Speech Technology*, p. 191, October 1984.

The types of speech knowledge needed for high-performance automatic speech recognition (ASR) and synthesis are outlined. The main lines of development of current speech recognition methods are sketched, emphasizing the 'stochastic model' approach. The possible role of speech synthesis as a basis for speech recognition is discussed. Further developments aimed at improving performance towards human listener levels are reported. A theme is the interaction between synthesis and

recognition: the most promising automatic speech recognition methods can be viewed as searches for the inputs to pattern synthesis systems that are most likely to generate the unknown speech patterns; current speech synthesis provides a useful basis for improved speech recognition models; and the latest idea in perception modelling is a parallel processing network that can behave as a recognizer or a synthesizer, depending on where the input is connected.

[Bridle 87]           Bridle, J. S., "Adaptive Networks and Speech Pattern Processing", *Pattern Recognition Theory and Applications*, pp. 221-222, June 1987, ISBN 0-387-17700-0.

[Bristow 86-1]       Bristow, Geoff, "The Speech Recognition Problem", pp.3-17, in: *Electronic Speech Recognition*, McGraw-Hill Inc., 1986, ISBN 0-07-007913-7.

[Bristow 86-2]       Bristow, G., *Electronic Speech Recognition: Techniques, Technology, and Applications*, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

[Bronson 85]         Bronson, E., and Jamieson, L. H., "A Distributed Parallel Architecture for Speech Understanding", *Algorithmically Specialized Parallel Computers*, pp. 139-148, Academic Press, Inc., 1985. ISBN 0-12-654130-2.

[Brown 87]           Brown, Evelyn, "Voice Recognition: A Promising New Technology", *Industrial Engineering*, v. 18, pp. 40-41, September 1986.

Looks at voice recognition highlighting the unlimited potential it holds for saving time and money as well as bolstering productivity as a technology that can complement bar coding and other forms of automatic identification.

[Bruce 82]           Bruce, B. C., *Natural Communications Between Person and Computer*, pp. 55-88, Lawrence Erlbaum Associates, 1982. ISBN 0-89859-191-0.

[Calcaterra 82]      Calcaterra, F., *Application of Artificial Intelligence in Voice Recognition Systems in Micro Computers*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1982. AD A115735.

This research investigates the use of inexpensive voice recognition systems hosted by microcomputers. The specific intent was to demonstrate a measurable and statistically significant improvement in the performance of relatively unsophisticated voice recognizers through the application of artificial intelligence algorithms to the recognition of software. Two

different artificial intelligence algorithms were studied, each with different levels of sophistication. Results showed that artificial intelligence can increase recognizer system reliability. The degree of improvement in correct recognition percentage varied with the amount of sophistication in the artificial intelligence algorithms

- [Cashen 86] Cashen, F., "Speech I/O Products Offer Board-Level Solutions", *Computer Design*, pp. 36-N40, 15 March, 1986.

Lower IC memory prices, more powerful digital processors, better algorithms, and a proliferation of personal computers are the many factors helping board-level speech I/O products come of age. Voice synthesis and recognition boards that plug into the expansion slots are now available for just a few hundred dollars.

- [Cater 84] Cater, J. P., *Electronically Hearing Computer Speech Recognition*, pp. 263+, Howard W. Sams & Co., Inc., 1984. ISBN 067222173X.

The subject of computer speech recognition covers eleven chapters in this book.

- [Cavazza 84] Cavazza, M., Ciaramella, A., and Pacifici, R., "Implementation of an Acoustical Front-End for Speech Recognition", *New Systems and Architectures for Automatic Speech Recognition and Synthesis*, pp. 215-223, Springer-Verlag New York, Inc., July 1984. ISBN 0-387-15177-X.

- [Cerf-Danon 87] Cerf-Danon, H., and others, "Speech Recognition Experiment with 10,000 Word Dictionary", *Pattern Recognition Theory and Applications*, pp. 203-209, June 1987. ISBN 0-387-17700-0.

- [Clements 87] Clements, Mark A., "Voice Recognition Systems Can Be Designed to Serve a Variety of Purposes", *Industrial Engineering*, v. 19, pp. 44+, September 1987.

Examines the technology of voice recognition, discusses the state of the art at present, criteria for choosing a system, and the tradeoffs that are necessary for this purpose.

- [Cochran 83] Cochran, D. J., and Riley, M. W., "Data Input By Voice", *Computer Industrial Engineering*, pp. 115-120, 1983.

- [Cole 85] National Technical Information Services PB87-214680/WCC, *Research on Feature-Based Systems for Speech Recognition*, by R. A. Cole, p. 17, July 1985.

The goals of the research were to (1) develop a system on a research computer to perform speaker-independent recognition of connected digits, (2) analyze the algorithms to determine the processing and memory requirements of the system, and (3) determine the feasibility of building a hardware device to run the algorithms in real-time. All goals were either met or exceeded with the development of a powerful new technology for computer speech recognition. This technology is called feature-based recognition because the perceptually important features of the speech signal are used to make decisions about what was said.

Potential applications include voice telephone dialing, voice data entry, and voice control of devices and processes.

- [Connolly 86] Connolly, J., and others, "Automatic Speech Recognition Based on Spectrogram Reading", *International Journal of Man-Machine Studies*, v. 24, pp. 611-N621, June 1986.

An approach to the problem of automatic speech recognition based on spectrogram reading is described. Firstly, the process of spectrogram reading by humans is discussed, and experimental findings presented which confirm that it is possible to learn to carry out such a process with some success. Secondly, a knowledge-engineering approach to the automation of the linguistic transcription of spectrograms is described and some results are presented. It is concluded that the approach described here offers the promise of progress towards the automatic recognition of multi-speaker continuous speech.

- [Conrad 83] Conrad, Ann E., "Voice Systems Are A 'Sound' Investment", *Data Management*, v. 21, pp. 20-23, November 1983.

Cautions information processing managers to keep in mind several important evaluation criteria when implementing voice processing technology.

- [Cook 85] Cook, James, "Data Entry Via Voice Recognition", *Manufacturing Systems*, pp. 28+, 1985.

Discusses Speaker Dependent Recognition (SDR) technology now used in factory data collection applications

[Dabbagh 86] Dabbagh, H., Damper, R., and Guy, D., "Transparent Interfacing of Speech Recognizers to Microcomputers", *Microcomputers & Microsystems*, pp. 371-N376, September 1986.

[Damper 84] Damper, R. I., "Speech Technology and the Disabled", *Proceedings of the 1st International Conference of Speech Technology*, p. 135, October 1984.

Disabled people are likely to be among the earliest users of emergent speech technology. New capabilities of speech synthesis and recognition offer much promise in assisting disabled members of society to lead fuller lives, whether their handicap be sensory or physical. Speech synthesis can give the non-vocal a voice and make printed and "electronic" information accessible to the blind. Speech recognition devices, although having only rudimentary capability, are starting to make voice control of machines a practical proposition for people with limited physical ability. The deaf can also look forward to improved speech-reading ("lip-reading") aids based on new speech analysis hardware and software. However, there are many limitations to this technology and our understanding of how best to apply it. These difficulties are likely to severely curtail the success of attempts to harness speech technology to serve the disabled for some time to come.

[Damper 85] Damper, R., "Voice-Input Aids for the Physically Disabled", *International Journal of Man-Machine Studies*, pp. 541-553, 1985.

[De Mori 84] De Mori, R., and LaFace, P., "On the Use of Phonetic Knowledge for Automatic Speech Recognition", *New Systems and Architectures for Automatic Speech Recognition and Synthesis*, pp. 569-591, Springer-Verlag New York, Inc., pp. 2-14, July 1984. ISBN 0-387-15177-X.

[De Mori 85-1] De Mori, R., LaFace, P., and Mong, Y., "Parallel Algorithms for Syllable Recognition in Continuous Speech", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, pp. 56-69, January 1985.

[De Mori 85-2] De Mori, R., "Algorithms and Architectures for Speech Understanding", *Algorithmically Specialized Parallel Computers*, pp. 149-158, Academic Press, Inc., 1985. ISBN 0-12-654130-2.

[De Mori 85-3] De Mori, R., "Parallel Algorithms for Hypothesis Generation in Continuous Speech", *Computer Architectures for Spatially Distributed Data*, pp. 375-391, Springer-Verlag New York, Inc., 1985. ISBN 0-387-12886-7.

[De Mori 87-1] De Mori, R., Lam, L., and Probst, D., *Rule Based Detection of Speech Feature for Automatic Speech Recognition*, pp. 155-179, Cambridge University Press, 1987. ISBN 0-521-30983-2.

[De Mori 87-2] De Mori, R., "Knowledge-Based Computer Recognition of Speech", *Pattern Recognition Theory and Applications*, pp. 433-450, 9-20 June 1987. ISBN 0-387-17700-0.

[Dillman 84] Dillman, R., and others, "Reduction of Complexity in Speech Recognition", *Proceedings of the 1st International Conference of Speech Technology*, p.77, October 1984.

The development of speech recognition and speech synthesizer improves the quality of man-robot interaction essentially. For an unexperienced user it is easier to become familiar with speech communication than with the sometimes hard to understand typed "robot languages". Both programming of robots as well as verification of their actions (e.g., test of robot programs) can be supported by acoustical interfaces. In this paper a speech recognition and speech synthesizer system will be presented which has a high recognition rate, extendable vocabulary, a sentence generator, and an interface to robot controls. A fine state automata model is used to reduce the search space and time for speech recognition.

[DI Martino 84] DI Martino, J., "Dynamic Time Warping Algorithms for Isolated and Connected Word Recognition", *New Systems and Architectures for Automatic Speech Recognition and Synthesis*, pp. 405-418, Springer-Verlag New York, Inc., 2-14 July 1984. ISBN 0-387-15177-X

[EDP Anal 83] "Is "Voice" In Your Future Systems?" *EDP Analyzer*, v. 21, pp. 1-12, August 1983.

Discusses recent developments in the voice field such as the "processing" of voice messages and the appearance of new voice products making voice worth investigating for future information systems. Looks at four areas involved in voice processing, voice syntheses, voice recognition, voice mail, etc.

[Elenius 86] Elenius, K., and Blomberg, M., *Voice Input for Personal Computers*, pp. 361-372, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7

[Elster 80] Defense Technical Information Center, AD A106138, *The Effects of Certain Background Noise on the Performance of a Voice Recognition System*, by R. Elster, September 1980. NPS-55-80-010.

- [Epstein 86] Epstein, Jonathan, "Voice Recognition: Six Users Pioneer Cost-Saving Applications", *Computer World*, v. 20, pp. 79-82, 16 June 1986.

Points out that innovative users who design voice applications for their personal productivity find they have an exciting and profitable tool.

- [Eskenazi 83] Eskenazi, M., and Lienard, J. S., "Recognition of Steady-State French Sounds Pronounced by Several Speakers: Comparison of Human Performance and an Automatic Recognition Algorithm", *Speech Communication*, v. 2, n. 2-3, pp. 173-177, July 1983.

- [Fallside 85] Fallside, F., and Woods, W., *Computer Speech Processing*, p. 506, Prentice/Hall International, 1985. ISBN 0-13-163841-6.

- [Fallside 86] Fallside, F., Harrison, T., and Prager, R., "Boltzmann Machines for Speech Recognition", *Computer Speech and Language*, pp. 3-N27, March 1986.

- [Fisher 86] Fisher, M., *Voice Control for the Disabled*, pp. 309-321, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

- [Ford 83] National Technical Information Service 84003837, *How to Talk to Your Computer, Literally*, by W. Ford, p. 8, 1983. Department of Energy

Provides guidelines for selecting and using voice I/O hardware including vocabulary size, method of training, upload/download capabilities, user control of recognition parameters, package form factor, and information returned to the user.

- [Foster 82] Foster, Richard A., "A Word About Its Future", *Computer World Extra*, v. 16, pp. 39-40, 17 March 1982.

Discusses technological developments in voice recognition and response and explains how to determine whether a company has a need for it.

- [French 83] French, B. A., *Some Effects of Stress on Users of a Voice Recognition System: A Preliminary Inquiry*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1983. AD A128559.

This thesis is an attempt to see if placing users of such equipment under time-induced stress has an effect on their percent correct recognition rates.

[Friedman 84] Friedman, Elliot, "Voice Technology Coming for Microcomputers in 1984", *Computer World*, v. 18, p. 64, 30 April 1984.

Informes that, in 1984, voice applications for microcomputers will be broadly available for the first time, able to be integrated with other applications.

[Frison 84-1] Frison, P., and Quinton, P., "Systolic Architectures for Connected Speech Recognition", *New Systems and Architectures for Automatic Speech Recognition and Synthesis*, pp. 145-167, Springer-Verlag New York, Inc., 2-14 July 1984. ISBN 0-387-15177-X.

[Frison 84-2] Frison, P., "An Integrated Systolic Machine for Speech Recognition", *VLSI Algorithms and Architectures*, pp. 175-188, Elsevier Science Publishers Co., Inc., 1984. ISBN 0-444-87662-6.

[Good 84] Good, Robert A., "Voice Input/Output at Less Cost", *Systems & Software*, v. 3, pp. 141-144, May 1984.

Describes a new software package that speeds the development of voice I/O for the IBM PC and multichannel systems.

[Gould 83] Gould, J. D., and Boies, S. J., "Human Factors Challenges in Creating a Principal Support Office System-The Speech Filing System Approach", *ACM Transactions on Office Information Systems*, v. 1, pp. 273-298, October 1983.

This paper identifies the key behavioral challenges in designing principal-support office systems and our approaches to them. These challenges included designing a system which office principals would find useful and would directly use themselves. Ultimately, the system, called the Speech Filing System (SFS), became primarily a voice store and forward message system with which compose, edit, send, and receive audio messages, using telephones as terminals. Our approaches included behavioral analyses of principals' needs and irritations, controlled laboratory experiments, several years of training, observing, and interviewing hundreds of actual SFS users, several years of demonstrating SFS to thousands of potential users and receiving feedback, empirical studies of alternative methods of training and documentation, continual major modifications of the user interface, simulations of alternative user interface, and actual SFS usage analyses. The results indicate that SFS is now relatively easy to learn, solves real business problems, and leads to user satisfaction.

[GovDatSys 86] "Computers Have Learned To Listen", *Government Data Systems*, v. 15, pp. 86+, July/ August 1986.

Tells how breakthroughs in speech recognition have spurred search for VARs and integrators to develop applications.

[Green 83] Green, T. R. G., and others, "Friendly Interfacing to Simple Speech Recognizers", *Behavior and Information Technology*, pp. 23-38, January-March 1983.

[Green 85] Green, Phil, "Speech Recognition--What is Happening Now?", *Computer Bulletin*, v. 1, pp. 5-7, September 1985.

Points out that there is a widespread feeling in the speech research community that automatic speech recognition is rapidly coming of age.

[Gubrynowicz 84] Gubrynowicz, R., Le Guennec, L., and Mercier, G., *Detection and Recognition of Nasal Consonants in Continuous Speech--Preliminary Results*, pp. 613-628, Springer-Verlag New York, Inc., July 1984. ISBN 0-387-15177-X.

New systems and architectures for automatic speech recognition and synthesis

[Haas 84] Haas, M., "The Texas Speech Command System", *Byte*, pp. 341-348, June 1984.

You can now give voice commands to the TI Professional Computer or use it as an answering machine and a smart telephone.

[Hager 86] Hager, Peter, "Breakthroughs Said to be Ahead for Voice Recognition", *Government Computer News*, v. 5, p. 40, 29 August 1986.

Points out that the use of voice recognition as a means of inputting data is the most natural way to communicate with a computer, but it also offers users marked productivity gains over conventual keyboard input.

[Harrison 84] Harrison, J. A., "Evaluation, Assessment and Selection of Speech Products for Use in Applications", *Proceedings of the 1st International Conference of Speech Technology*, pp. 49-56, October 1984.

This paper offers pragmatic guidance to non speech specialists on the evaluation and assessment of the relative merits of speech products against an identified need. It covers the formulation of detailed requirements, the difficulties of specifying performance in simple terms, potential methods of

evaluation, and some pitfalls to avoid. It concludes with the opinion that the spread in the use of speech technology depends largely on non specialists learning to apply what is available.

[Haton 85]           Haton, J. P., "Artificial Intelligence for Automatic Speech Understanding", *Technology and the Science of Informatics*, pp. 265-287, May/June 1985.

[Haton 87]           Haton, J., *Fundamentals in Computer Understanding: Speech and Vision*, p. 276, Cambridge University Press, 1987. ISBN 0-521-30983-2.

[Henkle 83]          Henkle, Tom, "Fewer Firms Developing Voice Systems: IRD", *Computer World*, v. 17, pp. 10+, 17 January 1983.

Discusses why conversing computers are still not a reality.

[Hill 86]            Hill, E. T., and Kotowski, L. B., *Using Voice Recognition as an Input Medium to the JINTACCS Automated Message Preparation System (JAMPS)*, Masters Thesis, Naval Postgraduate School, Monterey, California, March 1986.

This thesis investigates the interfacing of voice recognition, also known as automatic speech recognition (ASR), with the Joint Interoperability of Tactical Command and Control Systems (JINTACCS) Automated Message Preparation System (JAMPS). The voice recognition system we used is the Texas Instruments (TI) TI-SPEECH (tm) imbedded in the Texas Instruments Portable Professional Computer (PPC). We were able to load the Joint Automated Message Preparation System software onto the Texas Instruments Portable Professional Computer hard disk. With the Vocabulary we built, we ran the Joint Automated Message Preparation System software on the Texas Instruments Portable Professional Computer using voice recognition. Our results indicate Automatic Speech Recognition has an application in message preparation during military operations. Automatic Speech Recognition could curtail the time to prepare messages, and thereby reduce the time element in the command and control process. We propose a measure of performance to test how much time might be saved by using Automatic Speech Recognition with Joint Automated Message Preparation System. We also suggest some areas for future research.

[Hobbs 84]          Hobbs, G. R., "The Application of Speech Input/Output to Training Simulations", *Proceedings of the 1st International Conference of Speech Technology*, p.121, October 1984.

In some command and control training situations the trainee is being instructed in a task which involves the use of a well defined and well structured command language to communicate with other people over a voice communications link. These training situations frequently require the use of additional experienced personnel to act as "stand-ins" at the end of the simulated link.

This paper describes the selection of a suitable application, the construction of and early experience with an experimental Air Traffic Control Trainer system, the first phase of which was completed early in the second quarter of 1984. The system uses speech recognition and synthesis under the control of a computer to simulate the action of the "stand-in", normally known as the blip driver in this type of system. The computer is also used to sequence the training scenario.

[Howell 83] Howell, P., "The Extent of Coarticulatory Effects: Implications for Models of Speech Recognition", *Speech Communications*, v. 2, n. 2-3, pp. 159-163, July 1983.

[Hunt 83] Hunt, M., Lenning, M., and Mermelstein, P., *Use of Dynamic Programming in a Syllable-Based Continuous Speech Recognition System*, pp. 163-188, Addison-Wesley Publishing Co., 1983. ISBN 0-201-07809-0.

[Hunter 85] Hunter, Phillip, "Speak and You Shall be Answered", *IBM User*, pp. 43+, November 1985.

Looks at voice recognition systems which are finally moving ahead due to recent breakthroughs in technology.

[Int Res Dev 80] International Resource Development, Inc., *Speech Recognition and Computer Voice Synthesis*, p. 177, 1980.

Explores present and future applications of speech recognition and synthesis including commercial applications. Current and potential suppliers are reviewed, with detailed information on shipment levels, market shares, and strategies included. Companies discussed include Threshold Technology, Perception Technology, IBM, and Verbex. Applications of large system integration technology for advanced speech recognition and synthesis are discussed.

[Int Res Dev 85] International Resource Development, Inc. Report 644, *Speech Recognition & Voice Synthesis*, 1985.

[Int Res Dev 87] International Resource Development, Inc. Report 702, *Corporate Talkwriters Voice Mail & Speech Processing in Office Automation*, 1987

[Ivall 86-1] Ivall, T., *Commercial Speech Recognizers*, pp. 216-233, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

[Ivall 86-2] Ivall, T., *Linking Recognizers to Computers*, pp. 234-243, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

[Jinper 85] Jinper, X., Feng, Y., and Zhiqiang, T., "A Speech Recognition Interface to a Microcomputer", *Chinese Journal of Computers*, pp. 213-222, 1985.

[Johnson 85] Johnson, S. R., Connolly, J. H., and Edmonds, E. A., "Spectrogram Analysis: A Knowledge-Based Approach to Automatic Speech Recognition", *Research and Development in Expert Systems*, pp. 95-103, Cambridge University Press, 1985. ISBN 0-89797-149-0.

[Johnson 86] Johnson, P., Long, J., and Visick, D., "Voice Versus Keyboard: Use of a Comparative Analysis of Learning to Identify Skill Requirements of Input Devices", *People and Computers: Designing for Usability*, pp. 546-562, Cambridge University Press, September 1986. ISBN 0-521-33259-1.

[Joost 83] Joost, M. G., Hosni, Y. A., and Petry, F. E., "Voice Communication With Computers: A Primer", *Computers and Industrial Engineering*, pp. 101-114, 1983.

[Keller 85] Keller, Erik L., "Voice Recognition Starts Sounding Off", *Systems & Software*, v. 4, pp. 55+, March 1985.

Reports that voice recognition is being used increasingly in manufacturing applications due to price reduction, PC use, and interest by original-equipment manufacturers.

[Koelsch 87] Koelsch, James R., "Talk to Your Computer, It Understands", *Product Engineering*, pp. 44+, April 1987.

Reports that manufacturers often use computers to prompt machine operators, and to verify that workers enter data correctly.

[Kohonen 84] Kohonen, T., and others, "On-Line Recognition of Spoken Words from a Large Vocabulary", *Information Sciences: An International Journal*, v. 33, pp. 3-30, 1984.

It is demonstrated in this paper that a real-time, large-vocabulary, isolated-word speech recognition system can effectively be implemented using the following two-stage organization: (1) conversion of the speech signal into phonemic transcriptions, (2) recognition of phonemic transcriptions by advanced searching methods. A comparison of several alternatives for the first stage has indicated that the best accuracy is achieved by the learning-subspace method.

For the second stage the authors recommend fast string searching by redundant hash addressing combined with subsequent probabilistic analysis. The above system has been implemented in a minicomputer environment.

[Korzeniowski 86] Korzeniowski, Paul, "First User not Mum", *Networks World*, v. 3, pp. 13-14, 24 March 1986.

Looks at AT&T's pilot project Conversant 1 Voice System, a speech recognition system that allows users to input data via spoken words which the system translates into data.

[Kurzweil 86] Kurzweil, R., "The Technology of the Kurzweil Voice Writer", *Byte*, pp. 177-N186, March 1986.

The present office system provides a clue to future applications for the deaf.

[Kuzela 86] Kuzela, Lad, "Voice Technology: Now They're Listening", *Industrial Week*, v. 229, pp. 35-37, 28 April 1986.

Shows that after years of disappointing responses in courting potential users, vendors of computerized voice systems are now making headway.

[Lea 86] Lea, W., "The Elements of Speech Recognition", pp. 49-129, in: *Electronic Speech Recognition*, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

[LeFever 87] LeFever, Michael A., *Speech Recognition in a Command and Control Workstation Environment*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1987.

This thesis investigates speech recognition in a command and control workstation environment. It discusses the Navy's need for a command and control workstation (CCWS) and the importance of the human interface design.

- [Leggett 82] Leggett, John Joseph, "An Empirical Investigation of Voice as an Input Modality for Computer Programming", *Computer Science*, v.13, p. 366, 1982. UMI order number: DA 83-06794.

This dissertation discusses the design, implementation, and results of a controlled experiment to evaluate voice versus keyboard (the standard input mode) in a language-directed editing environment. Twenty-four subjects input and edited program segments under control of a language-directed editor via the two input modes. Measures of speed, accuracy, and efficiency were used to compare the two modes of input.

- [Levinson 86] Levinson, S., "Continuously Variable Duration Hidden Markov Models for Automatic Speech Recognition", *Computer Speech and Language*, pp. 29-N45, March 1986.

- [Llaurado 82] Llaurado, J.G., "Computerized Speech Recognition", *International Journal Bio-Medical Computing*, pp. 91-94, March 1982.

- [Lombardo 84] Lombardo, J. P., *Using Continuous Voice Recognition Technology as Input Medium to the Naval Warfare Interactive Support System (NWISS)*, Master's Thesis, Naval Postgraduate School, Monterey, California, April 1984. AD A7916.

A great deal of research has been conducted in the past 20 years concerning the use of voice recognition equipment with computers. The goal of this research has been to improve the man-machine interface. With the breakthrough from discrete to continuous voice recognition technology in the 1970s, a large step toward that goal was taken.

This thesis attempts to show that continuous voice recognition technology can be effectively applied in a highly interactive, computer-aided wargaming environment. Through analysis of the strictly-formatted command syntax of the Naval Warfare Interactive Simulation System (NWISS) and use of commercially available, innovative, continuous speech hardware and software, a new input medium was created for the user of that wargame. The true effectiveness of this application of voice recognition technology must still be tested. Plans for such testing are being made and, to that extent, the thesis objectives are partly met.

- [Longuet-Higgins 85] Longuet-Higgins, C., *Tones of Voice: The Role of Information in Computer Speech Understanding*, pp. 293-304, Prentice/Hall International, 1985. ISBN 0-13-163841-6.

- [Lundquist 82]      Lundquist, Eric, "Voice-Input Systems Make Inroads into Industrial Applications-Manufacturing", *Mini Systems*, pp. 165+, October 1982.

Suggests that voice-input systems are becoming more attractive; they are more reliable, cost less and have overcome hurdles of past efforts.

- [Mackie 87]      Mackie, K., Katsch, R., and Dermody, P., "Assessment of Evaluation Measures for Processed Speech", *Speech Communication*, v. 6, n. 4, pp. 309-316, 1 December 1987.

The present study uses a range of speech intelligibility measures to examine their effectiveness in the evaluation of highly intelligible processed speech. The results show that speech stimuli which are not differentiated by traditional intelligibility measures can be differentiated by more sensitive test methodologies. The results indicate the value of including more sensitive tests of speech intelligibility in evaluation protocols for processed speech.

- [Madron 84]      Madron, Thomas, "Speech Systems Gaining Ground", *Computer World*, v. 18, pp. 73-74, 6 February 1984.

Focuses on speech systems, and predicts that they are likely to become the major new I/O device of microcomputing in the middle to late 1980s.

- [Maenobu 84]      Maenobu, K., "Speaker-Independent Word Recognition in Connected Speech on the Basis of Phoneme Recognition", *Automatic Speech Recognition*, pp. 31-62, July/August 1984.

- [Mariani 83]      Mariani, J., and others, "A Man-Machine Speech Communication System Including Word Based Recognition and Text-to-Speech Synthesis", *Proceedings of the IFIP World Computer Congress*, pp. 673-679, 1983.

Presents a man-machine speech communication system which is composed of a speech recognition module and a speech synthesis module, each implanted on a single board and using microprocessors. 18 references.

- [Martin 84]      Martin, B. J., and Poock, G. K., "An Initial Applied Look at Stress and Voice Recognition", *Journal of the American Voice Input/Output Society*, v. 1, pp. 24-33, June 1984.

- [Martin 86]      Martin, S., "Difficult Speech-Recognition Technology Shows Signs of Maturity", *Computer Design*, pp. 23-N29, 1 August 1986.

Speech synthesis/recognition is acknowledged as a powerful and natural human interface to a computer, and the economic fuel that funded past research is now being applied to product development as well.

- [Mascarenas 84] Mascarenas, John, "Voice Processing Creates a New Dimension in Speech: The Ability to Talk Without a Tongue", *Computer World On Communications*, v. 1, pp. 50-52, November 1984.

Discusses the new technology that implements speech communications with computers and spans such applications as voice synthesis, voice recognition, and voice and text processing.

- [Mavaddat 85] Mavaddat, F., and Cheng, S. K. S., "Word Recognition in a Reduced Linear Prediction Space", *Pattern Recognition Letters*, pp. 185-190. May 1985.

- [McCracken 81] McCracken, Donald L., *A Production System Version of Hearsay-II Speech Understanding System*, p. 139, UMI Research Press, 1981.

Describes a detailed comparison of a reimplementaion of the speech understanding system, HEARSAY-II, with its predecessor.

- [Meade 85] Meade, Jim, "Winning Small in Voice Recognition", *Hardcopy*, v. 14, pp. 20+, November 1985.

Reports that by taking a limited vocabulary approach to voice recognition, DEC has engineered a viable adjunct to DECtalk.

- [Meisel 84] Meisel, W. S., "Speech-to-Text-Systems--The User's Needs", *Proceedings of the 1st International Conference of Speech Technology*, p.161, October 1984.

A large vocabulary continuous speech recognition system which transcribes speech to computer-readable text is an attractive objective. It would allow a user to get his ideas in a computer without typing. In a practical product, limitations on vocabulary, accuracy, and the user's freedom to speak naturally diverge from the ideal. This article discusses acceptance of a speech-to-text product, and the probable time frame in which initial products will be available.

- [Meisel 86] Meisel, W., *Towards The "Talkwriter"*, pp. 338-348, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

- [Meloni 83] Meloni, H., and Guizol, J., "Identifying Pseudo-Phonetic Events for Automatic Word Recognition", (FRENCH), *Speech Communication*, v. 2, n. 2-3, pp. 211-214, July 1983.

This paper describes the pseudo-phonetic decoding level of a speech recognition system. The signal representation is obtained by means of spectral and temporal parameters. Automatic segmentation and labeling algorithms produce a sequence of pseudo-phonetic classes which characterize the steady and transient parts of speech sounds. The definition of these segments is made up with pseudo-phonetic features. Prosodic information is carried out by some labels assigned to vocalic events.

- [Meloni 87] Meloni, H., Gispert, J., and Guizoni, J., "An Expert System for Analytic Word Identification in Continuous Speech", *Expert Systems & Their Applications, 5th International Workshop*, v. 2, pp. 1239-1250, Agence de l'Informatique, 13-15 May 1987. ISBN 2-86581-0283-X.

- [Menke 87] Menke, Susan M., "Voice Recognition Applications Will Increase in 1987", *Government Computer News*, v. 6, pp. 44-45, 16 January 1987.

Suggests that by the turn of the century speaker-independent continuous voice recognition software is expected to contain a large enough vocabulary for general office use; in the meantime, voice systems, with all their problems, are being used in a variety of applications now.

- [Minault 87] Minault, S., and others, "An Expert System for Speech Recognition by Signal Segmentation", *Expert Systems & Their Applications: 5th International Workshop*, v. 2, pp. 1251-1266, Agence de l'Informatique, 13-15 May 1987. ISBN 2-86581-0283-X.

- [Mod Mat 83] "Voice Recognition--Back Again, and Better," *Modern Materials Handling*, v. 38, pp. 52-53, 6 April 1983.

Contends that in the near future voice recognition will be at the heart of office automation and communication networks.

- [Mokhoff 84] Mokhoff, N., "Voice I/O Adds New Dimension to Computer Interface", *Computer Design*, pp. 19-21, March 1984.

- [Moody 85] Moody, H. Gerald, "Voice Recognition: At the Threshold", *Information Strategy*, v. 1, pp. 40-42, Summer 1985.

Reports that while progress in voice recognition technology has been limited, the flurry of new product offerings in recent months may be a harbinger of faster progress in the future.

- [Moore 84-1] Moore, R., "Overview of Speech Input", *Proceedings of the 1st International Conference of Speech Technology*, p. 25, October 1984.

This paper is intended to provide a brief insight into some of the techniques that underlie contemporary automatic speech recognition systems. It is shown how the concept of 'whole-word pattern matching' has established itself as an important principle, and a range of such algorithms is discussed. It is also shown how techniques for isolated word recognition may be extended to the recognition of connected speech. It is concluded that, although current automatic speech recognition algorithms are still relatively unsophisticated, they nevertheless exhibit a level of performance which can be useful in a wide range of well constrained task environments.

- [Moore 84-2] Moore, R., "Systems for Isolated and Connected Recognition", *New Systems and Architectures for Automatic Speech Recognition and Synthesis*, pp. 73-143, Springer-Verlag New York, Inc., 2-14 July 1984. ISBN 0-387-15177-X.

- [Murveit 83] Murveit, Hyman Jack, "An Integrated Circuit Based Speech Recognition System", *Electronics and Electrical Engineering*, v. 15, p. 96, 1983, UMI order number: AD A84-13527.

A high performance, flexible, and potentially inexpensive speech recognition system is described in this report. The system is based on two special-purpose integrated circuits that perform the speech recognition algorithms very efficiently. One of these integrated circuits is the front-end processor. It computes spectral coefficients from incoming speech, normalizes these spectra and finds the start and end of words in the speech. It transmits these spectra to a second integrated circuit that compares them with spectra from a set of stored word templates. The system can compare an input word with one thousand word templates and respond to a user within one quarter of a second. The system normally responds to words spoken in isolation from a particular speaker; however it can be used with connected speech as well as in a speaker independent manner. Modifying speech recognition algorithms to work with specially designed integrated circuits is shown to permit even high performance algorithms to be performed inexpensively. Using techniques such as these speech recognition devices should have a large range of applications within the next few years.

- [Myers 83] Myers, Edith, "If We Could Talk to the Terminals..." *Datamation*, v. 29, pp. 181+, October 1983.

Presents an overview of the many companies that are working towards voice recognition as a necessary part of office automation.

- [Nakagawa 84] Nakagawa, S. I., "Connected Spoken Word Recognition Algorithms by Constant Time Delay DP,  $O(n)$  DP and Augmented Continuous DP Matching", *Information Sciences: An International Journal*, pp. 63-86, July/August 1984.

- [Neil 81] National Technology Information Service AD A103280, NPS-55-81-003, *Examination of Voice Recognition System to Function in a Bilingual Mode*, by D. E. Neil, and T., Andreason, February 1981.

- [Niemann 84] Niemann, H., and others, "The Speech Understanding and Dialog System EVAR", *New Systems and Architectures for Automatic Speech Recognition and Synthesis*, pp. 271-302, Springer-Verlag New York, Inc., 2-14 July 1984. ISBN 0-387-15177-X.

- [Niemann 85] Niemann, H., and others, "A System for Understanding Continuous German Speech", *Information Sciences: An International Journal*, pp. 87-113, 1985.

- [Nishida 86] Nishida, S., "Speech Recognition Enhancement by Lip Information", *SIGCHI Bulletin*, pp. 198-N204, April 1986.

- [Nocerino 85] Nocerino, N., and others, "Comparative Study for Several Distortion Measures of Speech Recognition", *Speech Communication*, v. 4, n. 4, pp. 317-331, December 1985.

Local spectral distortion measures are commonly used to measure the similarity (or spectral distance) between two given short-time spectra. In this study we compared several different distortion measures including the Itakura-Saito (IS) distortion measure, the log likelihood ratio (LLR) distortion measure, the likelihood ratio (LR) distortion measure, the cepstral (CEP) distortion measure, and two proposed perceptually based distortion measures, the weighted Likelihood Ratio (WLR) and the weighted slope metric (WSM) distortion measures, in terms of their effects on the performance of a standard dynamic time warping (DTW) based, isolated word, speech recognizer. Two modifications of the basic forms of each measure were also investigated, namely, a Bark-scale frequency warping and the incorporation of suprasegmental energy information. All distortion measures and their modifications were tested on an alpha-digit vocabulary,

4-talker, telephone recording data base. The results can be summarized as: (1) All LCP-based distortion measures performed reasonably well. The LLR and WSM distortion measures gave the highest recognition accuracy, while the IS distortion measure gave the lowest score; (2) Whereas the addition of suprasegmental energy information helped the recognition performance, the use of gain and absolute loudness degraded the performance; (3) Bark-scale frequency warping did not, at least for the highly bandlimited telephone data base we tested, perform as well as its unwarped counterpart; (4) The WLR distortion measure did not perform as well as its unweighted counterpart.

[NTIS 81]            National Technical Information Service PB82-801051, *Speech Recognition by Computer*, p. 300, October 1981.

Presents investigations on the recognition, synthesis, and processing of speech by computer and includes research on the acoustical, phonological, and linguistics processes necessary in the conversion of the various waveforms by computers, in a bibliography containing 294 citations.

[NTIS 86-1]        National Technical Information Service PB86-852787/WLI, *Speech Synthesis and Speech Recognition by Computer, January 1985-December 1985*, (Citations from the INSPEC: Information Services for the Physics and Engineering Communities Database), p. 166, December 1985.

Provides a bibliography that contains citations concerning the principles, designs, development, and various applications of computerized speech synthesis and speech recognition.

[NTIS 86-2]        National Technical Information Service PB86-871498/WLI, *Computer Voice Recognition: Market Aspects, 1983-June 1986* (Citations from the Computer Database), p. 52, July 1986.

Contains citations concerning market aspects of voice recognition technology, discussing applications in manufacturing, finance, telecommunications.

[NTIS 86-3]        National Technical Information Service PB86- 871704/WLI, *Speech Recognition by Computer, October 1981-July 1986*, (Citations from the Computer Database), p. 46, July 1986.

Contains a bibliography of citations concerning research and development efforts in the computer recognition of speech signals.

- [NTIS 86-4] National Technical Information Service PB86-852779/WLI, *Speech Synthesis and Speech Recognition by Computer, April 1983-1984* (Citations from the INSPEC: Information Services for the Physics and Engineering Communities Database), p. 248, December 1985.

Provides a bibliography that contains citations concerning the principals, designs, development, and various applications of computerized speech synthesis and speech recognition.

- [NTIS 87-1] National Technical Information Service PB87-864047/WCC, *Computer Voice Recognition: Market Aspects, January 1983 to July 1987*, (Citations from the Computer Database), p. 76, July 1987.

Includes an updated bibliography of citations concerning market aspects of voice recognition technology.

- [O'Neil 82] O'Neil, Edward F., "Voice Entry: Terminals You Can Talk To", *Data Communications*, v. 11, pp. 133+, October 1982.

Reports on the increasing feasibility of voice-entry technology; presents some applications in which voice recognition is used.

- [Ogozalek 86] Ogozalek, V., and Van Praag, J., "Comparison of Elderly and Younger Users on Keyboard and Voice Input Computer-Based Composition Tasks", *SIGCHI Bulletin ACM*, pp. 205-N211, April 1986.

- [Osman 83] Osman, G., "An Exchange Protocol for Continuous Speech Recognition and Synthesis System", *Computer-Aided Design of Multivariable Technological Systems*, pp. 285-288, Pergamon Press, 1983. ISBN 0-08-029357-3.

- [Paddock 83] Paddock, Harold E., "Voice Input: A Reality", *The Internal Auditor*, v. 40, pp. 23-26, December 1983.

Argues that the advantages of automatic speech recognition are so great that devices capable of recognizing isolated words or short phrases from a vocabulary of between 10 and 30 words are economically practical in some applications.

- [Pallett 85] Pallett, D. S., "Performance Assessment of Automatic Speech Recognizers", *Journal of Research of the National Bureau of Standards*, v. 90, pp. 371-N387, September- October 1985.

This paper discusses the factors known to influence the performance of automatic speech recognizers and describes test procedures for characterizing their performance. It is directed toward all the stakeholders in the speech community (researchers, vendors, and users); consequently, the discussion of test procedures is not directed toward the needs of specific users to demonstrate the performances characteristics of any specific algorithmic approach or particular product. It relies significantly on contributions from an emerging consensus standards activity, especially material developed within the IEEE Working Group on Speech I/O Performance Assessment.

[Pallett 86]            Pallett, D., *Assessing the Performance of Recognizers*, pp. 277-308, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

[Pay 81]              Pay, B. E., and Evans, C. R., "An Approach to the Automatic Recognition of Speech", *International Journal of Man-Machine Studies* v. 14, pp. 13-27, January 1981.

This paper describes some techniques employed at the National Physics Laboratory in developing a practical system capable of recognizing human speech. The system, which is currently being evaluated in an extended series of trials, is capable of performing two main tasks: (1) recognizing key words embedded in continuous speech and (2) segmenting and recognizing continuous speech such as strings of numerals.

[Pearkins 84]        Pearkins, Jon, "Talking Replaces Keyboarding", *Computer Data*, v. 9, p. 18, March 1984.

Discusses the changes that will take place in computers and their use in the next five to ten years, and emphasizes the need to be aware of these changes when doing long-range planning.

[Peckham 83]        Peckham, Jeremy, "The Logos Continuous Speech Recognition System", *Computer Bulletin*, pp. 2-3, March 1983.

Discusses Logos, one of the world's most advanced speech recognition systems, which was developed by Logics.

[Peckham 84]        Peckham, J. B., "Speech Recognition--What is it Worth?" *Proceedings of the 1st International Conference of Speech Technology*, p. 39, October 1984.

It is often assumed that, since speech is man's most natural means of communicating, it is the ideal medium for communicating with machines. This paper addresses the issue of assessing the true worth of speech input in

the man-machine interface and proposes transaction time as one objective measure. The economics of using speech input technology, related to its potential advantage over more traditional tactile input methods and different application markets, is also covered.

[Peckman 86] Peckman, J., *Human Factors in Speech Recognition*, pp. 172-190, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

[Pfauth 83] Pfauth, M., and Fisher, W. M., "Voice Recognition Enters The Control Room", *Control Engineering*, pp. 147-150, September 1983.

Voice recognition is at the door waiting to enter the industrial control room. As this formerly esoteric technology crosses the threshold from laboratory curiosity to practical equipment, otherwise mundane, task-intensive workplaces will become exciting, synergistic, and more productive.

[Philip 87] Philip, George and Young, Elizabeth S., "Man-Machine Interaction by Voice: Developments in Speech Technology", *Journal of Informational Sciences* v. 13, n. 1, pp. 3-23, 1987.

Outlines the limitations of existing means of communications with computers and the background to developments in voice input/output technology.

[Pierrel 87] Pierrel, J., *Aspects of Man-Machine Voice Dialog*, pp. 249-274, Cambridge University Press, 1987. ISBN 0-521-30983-2.

[Pister-Bourjot 87] Pister-Bourjot, C., and Haton, J., "Automatic Learning: An Approach to the Adaptation of a Speech Recognition System to One or Several Speakers", *Speech Communication*, v. 6, n. 1, pp. 43-54, 1 March 1987.

As part of a system for the automatic recognition of isolated words in a large vocabulary on the basis of an analytical approach, we considered the automatic speaker-adaptation of the system. This was carried out by means of an automatic learning procedure of the speakers' reference patterns, and by automatically adjusting the parameters of the system. This learning relies on a time alignment algorithm using acoustic-phonetic features which are little speaker dependent. The learning session was successfully tested on 18 speakers out of 20 (10 women and 10 men) and the reference patterns thus obtained yielded good results during the recognition phase. We have now undertaken an analysis of the vowels by 15 speakers based upon descriptive statistics and statistical interpretation in order to design procedures of

normalization and of automatic generation of a speaker's vowel reference patterns.

- [Pluhar 83] Pluhar, Kenneth, "Speech Recognition--An Exploding Future for the Man-Machine Interface", *Control Engineering*, pp. 70-73, January 1983.

Discusses the application of speech recognition systems to industrial control problems.

- [Pooch 80] National Technology Information Service AD A091055, NPS-55-80-016, *Experiments with Voice Input for Command and Control: Using Voice Input to Operate a Distributed Computer Network*, by G. K. Pooch, April 1980.

This report describes and experiment in which subjects used voice recognition equipment to verbally enter commands to a computer network similar to that of a command and control center or shipboard information center.

- [Pooch 81-1] Pooch, G. K., "To Train Randomly or All at Once... That is the Question", *Proceedings of Voice Data Entry Systems Applications Conference*, October 1981. (Sponsored by Lockheed Missiles and Space Co., Santa Clara, California.)

- [Pooch 81-2] National Technology Information Service AD A102208, NPS-55-81-013, *A Longitudinal Study of Computer Voice Recognition Performance and Vocabulary Size*, by G. K. Pooch, June 1981.

This research examined voice recognition performance as a function of time and showed no decrement in performance after 21 weeks. In addition, vocabulary sizes up to 240 utterances showed stable performance.

- [Pooch 83-1] National Technology Information Service AD A130155, *Voice Recognition Performance With Naive Versus Practiced Users*, by G. K. Pooch and B. J. Martin, June 1983.

- [Pooch 83-2] National Technology Information Service, NPS-55-83-012PR, *Simulated TACFIRE Input Procedure for Use With Voice Data Entry*, by G. K. Pooch and E. F. Roland, April 1983.

- [Pooch 83-3] National Technology Information Service AD A129951, NPS-55-83-005, *Wearing Army Gas Masks While Talking to a Voice Recognition System*, by G. K. Pooch and E. F. Roland, March 1983.

[Poock 83-4] National Technology Information Service NPS-55-83-017PR, *Final Summary: Voice Recognition/Input Issues for TACFIRE*, by G. K. Poock and E. F. Roland, March 1983.

[Poock 83-5] National Technology Information Service AD A127223 NPS-55-83-003, *The Effect of Feedback to Users of Voice Recognition Equipment*, by G. K. Poock and B. J. Martin, February 1983.

[Poock 83-6] National Technology Information Service AD A129975, NPS-55-83-001, *Voice Recognition Vocabulary Lists for the Army's TACFIRE System*, by G. K. Poock and E. F. Roland, January 1983.

[Poock 83-7] Poock, G. K., "Speech Recognition Research, Applications and International Efforts", *Human Factors Society*, Spring 1983.

Discusses a broad overview of the speech I/O industry on a national and international level. Within this context, technical and human factors issues which are relevant in all countries are discussed.

[Poock 84] National Technology Information Service AD A142554, NPS55-84-002, *Effects of Emotional and Perceptual Motor Stress on a Voice Recognition System's Accuracy: An Applied Investigation*, by G. K. Poock and B. J. Martin, February 1984. .

[Poock 85] National Technology Information Service, AD A158001, NPS55-85-012, *An Examination of Some Error Correcting Techniques for Continuous Speech Recognition Technology*, by G. K. Poock and B. J. Martin, June 1985.

[Poock 86] Poock, G. K., "A Longitudinal Study of Five Year Old Speech Reference Patterns", *Journal of the American Voice I/O Society*, v. 3, pp. 13-18, June 1986.

[Prasad 87] Prasad, K., and Lamba, T., "Natural Language Interfaces Based on Keyboard Extraction Using AWK", *Microprocessors & Microsystems*, pp. 157-160, 1 April 1987.

[Pursley 85] Pursley, Roy, "Speech Technology--No Longer Small Talk for Financial Software Users", *Journal of Financial Software*, v. 2, pp. 52-53, March/April 1985.

Points out that speech technology as a means of interfacing with a computer is particularly well-suited to use in the financial world.

[Quarmby 86] Quarmby, D., *Silicon Devices for Speech Recognition*, pp. 200-215, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

[Reardon 87] Reardon, Tracey A., "Talk About Productivity", *Words*, v. 15, pp. 22-23, December/January 1987.

Discusses PC-based voice recognition and voice response technology and how it enhances the way users do business.

[Rehsoft 84] Rehsoft, C., "Voice Recognition at the Ford Warehouse in Cologne", *Proceedings of the 1st International Conference of Speech Technology*, p. 103, October 1984.

Voice recognition has proved to be effective with an online shipping system at the Ford parts distribution center in Cologne. As one of the very few applications of this technology in Europe this center employs eight parallel workstations using voice recognition. This paper describes the system, especially the hardware and software used, and deals with ergonomic aspects to be observed when introducing voice recognition to the factory floor. The emphasis of this description is on the results of the system obtained at Ford and the consequences drawn from them for the introduction of voice recognition in general.

[Reuhkala 83] Reuhkala, E., "Recognition of Strings of Discrete Symbols With Special Application to Isolated Word Recognition", *Acta Polytechnica Scandinavica*, pp. 1-92, 1983.

[Rigoll 84] Rigoll, G., "Experiences in Interfacing Voice-Input/Output Devices to Host Computers, NC-Machines and Robots", *Proceedings of the 1st International Conference of Speech Technology*, p. 93, October 1984.

The Fraunhofer-Institut für Arbeitswirtschaft und Organisation (IAO) in Stuttgart performs contract research for industry and government. Several projects were carried out, concerning the integration of voice-input/output equipment into office automation and production systems, using various voice-input/output device and chip-sets. Among these projects was the use of a voice-input device and a voice output board for NC-machine programming, the integration of voice-input technology in quality control. The experiences concerning the industrial application of voice-input/output technology and the difficulties in interfacing the devices are presented in this paper.

- [Rigsby 82] Rigsby, Mike, *Verbal Control With Microcomputers*, p. 312, Tab Books, 1982.

Provides an overview of speech and the problem it presents for machine recognition and a "hands-on" guide for operating a microcomputer that recognizes and responds to voice commands.

- [Roberts 86] Roberts, L., and others, "Improving Speaker Consistency in an Automatic Speech Recognition Framework", *Computer Speech and Language*, pp. 61-N93, March 1986.

- [Rollins 83] Rollins, A., Constantine, B., and Baker, S., "Speech Recognition at Two Field Sites, Chi '83", *Human Factors in Computing Systems*, pp. 267-273, 1983. ISBN 0-89791-121-0.

- [Rollins 85] Rollins, A. M., "Speech Recognition and Manner of Speaking in Noise and in Quiet", *Human Factors in Computing Systems*, pp. 197-199, 14-18 April 1985. ISBN 0-89791-149-0.

- [Ross 84] Ross, Steve, and MacAllister, Jeff, "Practical and Continuous Speech Recognition", *Computer Design*, v. 23, pp. 69+, 15 June 1984.

Presents a continuous speech recognition system that accepts sentences of any length, and permits cost-effective voice-data entry in demanding real-world environments.

- [Rossi 83] Rossi, M., Nishinuma, Y., and Mercier, G., "Multi Speaker", (FRENCH), *Speech Communication*, v. 2, n. 2-3, pp. 215-217, July 1983.

We present an algorithm for the recognition of vowels using acoustic cues other than formant values. The acoustic cues presented make use of information relative to the spectral or temporal distribution of energy. These cues are context-independent and we obtained a mean rate of recognition of 92% for several speakers. The most efficient cues were those of the features open/close and front/back; the cues of nasality, on the other hand, showed greater intersubject variability and defined distinct classes of speakers. The context independency of the cues with isolated words leads us to expect good results for continuous speech.

- [Saitta 83] Saitta, L., "Experiments in Evidence Composition in a Speech Understanding System", *International Journal of Man-Machine Studies*, v.19, pp. 19-31, July 1983.

A method for composing partial evidences in pattern recognition problems is presented and experimental results, referring to speech understanding, are also discussed.

The method is well suited for real-time problems, where speed and parallelism in taking decisions are fundamental requirements. The case study presented in the paper is a simple one, for the sake of clarity, but a generalization to complex production systems can be easily obtained.

[Salfer 85] Salfer, D.L., *Voice Automation Of Ship Control*, Master's Thesis, Naval Postgraduate School, Monterey, California, September 1985.

This thesis explores possible shipboard application of speech recognition technology. It includes a detailed analysis of tasks performed on the bridge, in the Combat Information Center and in the main engineering control space of an FFG-7 Frigate.

[Santarelli 84] Santarelli, Mary-Beth, "Voice Recognition: Not Just a Lot of Talk", *Software News*, v. 4, pp. 44-45, December 1984.

Explains that while voice recognition has been successfully used in factories for quality assurance and inventory applications, it may not be sophisticated enough to be used in the office environment.

[Scagliola 83-1] Scagliola, C., "Continuous Speech Recognition Without Segmentation: Two Ways of Using Diphones as Basic Speech Units", *Speech Communication*, v. 2, n. 2-3, pp. 199-201, July 1983.

[Scagliola 83-2] Scagliola, C., "Language Models and Search algorithms for Real-Time Speech Recognition", *International Journal of Man-Machine Studies*, v. 22, pp. 523-547, 1983.

In this paper, the "continuous speech recognition" problem is given a clear mathematical formulation as the search for that sequence of basic speech units that best fits the input acoustic pattern. For this purpose spoken language models in the form of hierarchical transition networks are introduced, where lower level subnetworks describe the basic units as possible sequences of spectral states. The units adopted in this paper are either whole words or smaller subword elements, called diphones. The recognition problem thus becomes that of finding the best path through the network, a task carried out by the linguistic decoder. By using this approach, knowledge sources at different levels are strongly integrated. In this way, early decision making based on partial information (in particular any segmentation operation or the speech/silence distinction) is avoided:

usually this is a significant source of errors. Instead, decisions are deferred to the linguistic decoder, which possesses all the necessary pieces of information.

The properties that a linguistic decoder must possess in order to operate in real-time are listed, and then a best-few algorithm with partial traceback of explored paths, satisfying the above requisites, is described. In particular, the amount of storage needed is almost constant for any sentence length, and the interpretation of early words in a sentence may be possible long before the speaker has finished talking. Experimental results with two systems, one with words and the other with diphones as basic speech units, are reported. Finally, relative merits of words and diphones are discussed, taking into account aspects such as the storage and computing time requirements, their relative ability to deal with phonological variations and to discriminate between similar words, their speaker adaptation capability, and the ease with which it is possible to change the vocabulary and the language dependencies.

[Scagliola 84] Scagliola, C., and Marmi, L., "A Continuous Speech Recognition Based on a Diphone Spotting Approach", *Cybernetic Systems: Recognition, Learning, Self-Organization*, pp. 73-83, Research Studies Press, Ltd., 1984. ISBN 0-471-902195.

[Schalk 82] Schalk, Thomas B., Fantz, Gene A., and Woodson, Larry, "Voice Synthesis and Recognition", *Mini Systems*, v. 15, pp. 146+, December 1982.

[Schalk 83] Schalk, T. B., and Van Meir, E. L., "Terminals, Listen Up, Speech Recognition is a Reality", *Computer Decisions*, pp. 97-104, September 1983.

[Schmandt 85] Schmandt, C., *Voice Communication With Computers*, pp. 133-160, Ablex Publishing Company, 1985. ISBN 0-89381-244-1.

[Schotola 84] Schotola, T. "On the Use of Demisyllables in Automatic Word Recognition", *Speech Communication*, v. 3, n. 1, pp. 63-87, April 1984.

This paper describes experiments on automatic speech recognition using demisyllables as segmentation units and the consonant clusters contained therein as decision units for classification. As compared to the large number of different demisyllables, the use of consonant clusters reduces the class inventory considerably. In order to test the method, three experiments dealing with isolated German words were carried out. In the first experiment the syllabic segmentation of words was investigated; in the

second experiment the methods for classification of consonant clusters were tested. In the third experiment a complete 1000-word recognition system was developed which performed the segmentation, the classification of consonant clusters and vowels, and a correction of recognition errors by use of a phonetic lexicon. Demisyllables segmentation and processing have proved suitable, especially for large vocabularies.

- [Scott 83]            Scott, Brian L., "Voice Recognition Systems and Strategies", *Computer Designs*, v. 22, pp. 67-70, January 1983.

Describes word verification as an approach to voice recognition that overcomes the processing and memory-intensive demands of large system vocabularies.

- [Seaman 82]           Seaman, John, "Voice: New Ways With an Old Medium", *Computer Decisions*, v. 14, pp. 62+, March 1982.

Discusses applications of voice processing and describes voice processing equipment for data entry (recognition) and response (synthesis).

- [Seaman 83]           Seaman, John, "The Latest Word in Voice Recognition", *Computer Decision*, v. 15, pp. 48+, February 1983.

Examines the new Votan Model V5000 voice recognition and voice response unit.

- [Seaman 85]           Seaman, J., *Voice: New Ways With an Old Medium*, pp. 85-91, Havden Book Co., 1985. ISBN 0-8104-6329-6.

- [Senensieb 84]        Senensieb, G. A., "Speech Input and Output--A Survey of Available Products", *Proceedings of the 1st International Conference of Speech Technology*, p. 57, October 1984.

The capabilities of current speech input and output technology are explained and assessed with reference to a selection of existing products. Included in the survey are speech recognition products, single synthesizers, and text-to-speech systems. The tangible benefits of applying speech technology are summarized and the author's view of a challenge for the future is presented.

- [Shapiro 84]           Shapiro, E., "A Business Computer, A Business Program, and More on Voice Recognition", *Byte*, pp. 147-154, February 1984.

Recent developments raise some questions about perceived industry trends.

- [Shapiro 85] Shapiro, S. F., "Speech Recognition Produces Natural Interface", *Computer Design*, pp. 59-62, March 1985.
- [Shore 83] Shore, J. E. Burton, "Discrete Utterance Speech Recognition Without Time Alignment", *IEEE Transactions in Information Theory*, pp. 472-491, July 1983.
- [Silverman 85] Silverman, H. F., "One Architectural Approach for Speech Recognition Processors", *Algorithmically Specialized Parallel Computers*, pp. 129-148. Academic Press, Inc., 1985. ISBN 0-12-654130-2.
- [Siroux 85] Siroux, J., and Gillet, D., "A System for Man-Machine Communication Using Speech", *Speech Communication*, v. 4, pp.289-315, December 1985.

KEAL is a continuous speech recognition system developed at the CNET laboratory in Lannion (France). Part of the laboratory's current work aims at extending it in the direction of a speech-understanding and man-machine dialog system. A question-answer-type dialog is set in motion in order to provide the user with information (the current application consists in simulating a directory inquiries service). This paper describes how syntactic, semantic, and pragmatic knowledge is used for implementing such a dialog, and the main advantages and drawbacks of the methods chosen are discussed. Sentence recognition is performed by a left-to-right bottom-up parser by means of a semantic context-free grammar. Using a method analogous to that of semantic attributes, the parse-tree is then interpreted in order to obtain a semantic structure which represents the information relevant to the subsequent dialog. The dialog manager uses the semantic structure for instantiating a model graph, which represents the state the dialog at any instant; it indicates the next message to be sent to the user, and how to analyze his answer. An example derived from the directory inquiries service is described.

- [Smith 83] Smith, F. J., and Linggard, R. J., "Information Retrieval by Voice Input and Output", *Research and Development in Information Retrieval*, pp. 275-288, Springer-Verlag New York, Inc., 1983. ISBN 0-387-11978-7.
- [Smith 84] Smith, Emily T., and Harris, Marilyn A., "More Than a Whisper of Hope for Computers You Can Talk To", *Business Week*, p. 92F-H, 17 December 1984.

Examines the new IBM experimental computer which has a system capable of recognizing 5,000 spoken words with 95% accuracy.

- [Spine 84] Spine, T., Williges, B. H., and Maynard, J. F., "An Economical Approach to Modeling Speech Recognition Accuracy", *International Journal of Man-Machine Studies*, v. 21, pp. 191-202, September 1984.

Accuracy of speech recognizer decisions is an important criterion for maintaining both system effectiveness and user satisfaction. A central-composite design methodology is recommended as an economical means to develop empirical prediction equations for speech recognizer performance incorporating a number of influential factors. Factors manipulated in the central-composite design included number of training passes, reject threshold, difference score, and size of the active vocabulary. The factorial combination of two noncontinuous variables, sex of the speaker and inter-word confusability, was also investigated by replicating the central-composite design to create four sets of data. Standard least-squares multiple regression analysis was used to develop the four sets of prediction equations, each of which accounted for at least 50% of the variance in recognizer performance. A cross-validation study revealed that shrinkage was not excessive. Subsequently, these empirical models were incorporated into an interactive design tool for a dialogue author where the percentage of correct recognition is automatically optimized when the dialogue author enters the size of the vocabulary to be used or both the vocabulary size and desired number of training passes. The design tool can also be used to make predictions anywhere within the response surface. Use of these efficient data collection procedures along with the interactive design tool should greatly assist the dialogue author in predicting the impact of various language, task, environmental, algorithmic, human, and performance evaluation factors on speech recognition accuracy.

- [Stephens 83] Stephens, Ron, "Make the Way for Another Revolution", *Modern Offices*, v. 28, pp. 96+, October 1983.

Suggests that many of the current methods of communicating and manipulating information which have traditionally been dependent on keyboard entry, may soon be replaced by voice-based procedures, causing a major transformation with the automated office.

- [Strat Inc 81] *Voice Input/Output: Markets, Technologies & Applications*, p. 110, Strategic Inc., 1981.

Analyzes the advantages of voice I/O, states of the market technology trends in speech synthesis, future applications, voice response, text-to-voice, language translations, aids to handicapped and computer output. Electronic voice mail, dictation/word processing, computer I/O automation, games, etc., also are included.

- [Sweeney 86] Sweeney, M. J., and Bitar, K. J., *An Analysis of Friendly Input Devices for the Control of the Naval Warfare Interactive Simulation System*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1986. AD S9333.

This thesis describes an experiment conducted at the Naval Postgraduate School (NPS) during the period 15 October through 28 October 1985. Specifically, the experiment evaluates "pull-down window" micro-computer technology, continuous speech recognition equipment, and standard computer keyboard entry to input commands and control environment. Using the Naval Warfare Interactive Simulation System (NWISS) as a controlled medium, military problems were posed to test subjects in specific light and noise environments. Although the results are not entirely conclusive, they do demonstrate a distinct advantage in using continuous speech or keyboard entry modes over the drop-down window technology of the Macintosh (if subject training time is not a significant restriction). Either the continuous speech or the keyboard method was clearly superior in all environments.

- [Taggart 81] National Technical Information Service AD-A105 568, *Voice Recognition as an Input Modality for the TACCO Preflight Data Insertion Task in the P-3C Aircraft*, by John Laughlin Taggart and Charles Darwin Wolfe, Jr., p. 150, March 1981.

Reports the results of an experiment to compare accuracy and entry speed capabilities of a standard keyboard with the Threshold Technology T-600 voice recognition unit in the performance of an operational data entry task in the P-3C aircraft.

- [Tanaka 83] Tanaka, A., and others, "A Study of the Syllable Oriented Recognition of Continuous Speech", *Speech Communication*, v. 2, n. 2-3, pp. 207-210, July 1983.

- [Taylor 86] Taylor, M., *Voice Input Applications in Aerospace*, pp. 322-337, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

- [Tecosky 86] Tecosky, T., *Interfacing Standards for Recognizers*, pp. 244-255, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

- [Teja 83] Teja, E. R., and Gonnella, G., *Voice Recognition Technology*, p. 212, Reston Publishing Co., 1983. ISBN 0835984176.

- [Thompson 84] Thompson, H., "Artificial Intelligence and Speech Processing: The Good News and the Bad News", *Proceedings of the 1st International Conference of Speech Technology*, p. 217, October 1984.

Discusses author's expectations about the contributions we can and cannot expect from Artificial Intelligence to Speech Processing over the next few years.

- [Thompson 85] Thompson, Linde, "Voice Recognition Systems: A Sound Investment in the Future", *News 34-38*, pp. 59+, March 1985.

Looks at the present and the future uses of voice recognition.

- [Tyler 86] Tyler, J., "Speech Recognition System Using Walsh Analysis and Dynamic Programming", *Microcomputers & Microsystems*, pp. 427-N433, October 1986.

- [Underwood 84] Underwood, M. J., "Human Factors Aspects of Speech Technology", *Proceedings of the 1st International Conference of Speech Technology*, p. 223, October 1984.

Regards speech technology as a means to an end, and not an end in itself. Discusses the human component in the speech technology system and its importance.

- [Viglione 84] Viglione, S. S., "Trends in Development of Speech Recognition Systems", *Proceedings of the 1st International Conference of Speech Technology*, p. 169, October 1984.

Discusses the inherent superiority of speech over other modes of human communications and the growing need for better control of complex machines. Discusses the major role of man-machine communication through the use of speech recognition and speech response systems.

- [Viglione 86] Viglione, S., *Recognition Past and Future*, pp. 373-387, McGraw-Hill Inc., 1986. ISBN 0-07-007913-7.

Discusses the inherent superiority of speech over other modes of human communication and the growing need for better control of complex machines. discusses the major role of man-machine command through the use of speech recognition and speech response systems.

- [Visser 87] Visser, Roger, "Voice Recognition Fills Technical Barriers", *Manufacture Engineering*, v. 98, pp. CT-24 to CT-26, May 1987.

Discusses voice recognition, the technology which allows people to interact with computers using voice instead of keyboards and terminals and which has been successfully implemented by numerous manufacturers from steel and car makers to circuit board designers.

- [Wagner 87] Wagner, M., "A Speech Recognition Experiment With the Entire Syllable Inventory of Standard Chinese", *Speech Communication*, v. 6, pp. 363-369, 1 December 1987.

This paper explores the possibility of using automatic speech recognition as a front end to a computer for Chinese character processing. A speech recognition experiment has been performed with the complete inventory of second-tone syllables of Standard Chinese. Two recordings of this inventory, which were made 48 hours after one another, were used as test and reference sets. It is shown that the distribution of intrasyllable distances and the distribution of intersyllable distances overlap considerably for the full inventory of 260 second-tone syllables. The recognition rate was determined as a function of the syllable size and is 47.3% for the complete syllable inventory.

- [Watrous 85] Watrous, Raymond, "Speech Input/Output: Support for Integration," *Journal of Computer-Integrated Manufacturing Management*, v. 1, pp. 37-44, Spring 1985.

Describes the current status of speech I/O technology and defines some of the terminology associated with the technology followed by a discussion of the technology's advantages and successful use.

- [Wetterlind 86] Wetterlind, Peter James, "A Speech Error Correction Algorithm for Natural Language Input Processing", *Computer Science*, v. 17, p. 300, 1986, UMI order number: AD A86-25455.

This research experiment consisted of construction of a system for identifying a natural language sentence using only speaker independent phonemes as the input. The motivating hypothesis for the experiment is that spoken sentences can be recognized from limited phoneme input. The research system accepts only strings of consonant phonemes, which are recognizable in a speaker independent environment. The original 'spoken' sentence is reproduced from the consonant phonemes and formatted as a word sequence for subsequent transmission to a natural language processing system. The system uses a vocabulary of general words and an expandable dictionary of domain specific words during the sentence recognition process.

- [White 84] White, G. M., "Speech Recognition: An Idea Whose Time is Coming", *Byte*, pp. 213-225, January 1984.

Some theoretical and practical aspects of this emerging technology are presented.

- [Wilson 84] Wilson, J., "Where Do We Go from Here?", *Proceedings of the 1st International Conference of Speech Technology*, p. 181, October 1984.

Discusses the background and evolution of future speech technology products and services.

- [Williams 85] Williams, John M., "Computer Knows its Programmer's Voice", *Government Computer News*, v. 4, p. 32, 5 July 1985.

Discusses a quadriplegic's voice recognition system which allows him to perform the same tasks as other computer programmers.

- [Withers 83] Withers, S. J., "Voice Control of an Interactive Simulation", *Simulation*, pp. 28-29, January 1983.

A low cost, microcomputer-based voice recognition device makes a convenient input channel for an interactive model of a manufacturing system. The problems with current hardware are its limited capabilities and unreliable operation. However, the potential exists for useful voice control of simulations in the near future.

- [Wood 86] Wood, Lamont, "Voices in the Wilderness", *Computer Decisions*, v. 18, pp. 34+, 8 April 1986.

States that voice recognition is a long way from becoming a widely accepted office technology but, nevertheless, today's voice recognition systems do have valuable applications, especially on the shop floor and in the warehouse.

- [Woods 85] Woods, Tom, "Computers Learn to Listen", *Business Computer Systems*, v. 4, pp. 80+, March 1985.

Suggests that today's pioneering speech recognition products provide a glimpse of the exciting technologies and diverse business applications soon to come.

- [Wyatt 85] Wyatt, Jim, and Elbon, Dave, "Computers That Listen and Talk", *Cause/Effect*, v. 8, pp. 9+, July 1985.

Points out that when considering voice input/output, the terms voice storage and playback, voice recognition, and voice synthesis can be used to characterize tasks being performed, and explains.

[Yalabik 84] Yalabik, N., and Unal, F., "An Efficient Algorithm for Recognizing Isolated Turkish Words", *New Systems and Architectures for Automatic Speech Recognition and Synthesis*, pp. 419-426, 2-14 July 1984.

[Yannakoudakis 85] Yannakoudakis, E. J., "Voice I/O: Problems and Perspectives", *Computer Bulletin*, v. 1, pp.10-12, September 1985.

Discusses one University's approach to computer voice I/O with the playback or recognition of speech units through the application of rules in an algorithmic manner. 4 references.

[Yellen 83] Yellen, H. W., *A Preliminary Analysis of Human Factors Affecting the Recognition Accuracy of a Discrete Word Recognizer for C3 System*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1983. AD A128546.

Literature pertaining to voice recognition abounds with information relevant to the assessment to transitory speech recognition devices. In the past, engineering requirements have dictated the path this technology followed. But, other factors do exist that influence recognition accuracy. This thesis explores the impacts of human factors on the successful recognition of speech, principally addressing the differences or variability among users. A Threshold Technology T-600 was used for a 100 utterance vocabulary to test 44 subjects. A statistical analysis was conducted on five generic categories of human factors: occupational, operational, psychological, physiological, and personal. How the equipment is trained and the experience level of the speaker were found to be key characteristics influencing recognition accuracy. To a lesser extent computer experience, time of week, accent, vital capacity and rate of air flow, speaker cooperativeness, and anxiety were found to affect overall error rate.

[Zue 83] Zue, V. W., "The Use of Phonetic Rules in Automatic Speech Recognition", *Speech Communication*, v. 2, n. 2-3, pp. 181-186, July 1983.

[Zue 84] Zue, V. W., and Huttenlocher, D. P., "Computer Recognition of Isolated Words from Large Vocabularies: Lexical Access Using Partial Phonetic Information", *Institute of Information Science*, pp. 343-347, 1984

## APPENDIX C1 HUMAN FACTORS

### SECTION 1. HUMAN FACTORS

[Armstrong 80]	[Gould 83]	[Niemann 85]
[Baker 84]	[GovDatSys 86]	[Nishida 86]
[Berman 84]	[Green 83]	[NTIS 86-1]
[Blunden 80]	[Green 85]	[NTIS 86-2]
[Bristow 86-1]	[Hager 86]	[NTIS 86-3]
[Bristow 86-2]	[Harrison 84]	[NTIS 86-4]
[Brown 87]	[Hunter 85]	[NTIS 87-1]
[Bruce 82]	[Int Res Dev 35]	[O'Neil 82]
[Calcaterra 82]	[Int Res Dev 87]	[Ogozalek 86]
[Cashen 86]	[Ivall 86-1]	[Paddock 83]
[Cater 84]	[Ivall 86-2]	[Pallett 85]
[Cavazza 84]	[Johnson 86]	[Pallett 86]
[Cerf-Danon 87]	[Joost 83]	[Pearkins 84]
[Clements 87]	[Kohonen 85]	[Peckham 83]
[Conrad 83]	[Kurzweil 86]	[Peckman 86]
[Dabbagh 86]	[Lea 86]	[Philip 87]
[Dillman 84]	[Leggett 82]	[Pierrel 87]
[EDP Anal 83]	[Llaurado 82]	[Pluhar 83]
[Elenius 86]	[Martin 84]	[Pooock 81-2]
[Elster 80]	[Martin 86]	[Pooock 83-1]
[Epstein 86]	[Mascarenas 84]	[Pooock 83-3]
[Fallside 85]	[Meade 85]	[Pooock 83-5]
[Fallside 86]	[Meisel 84]	[Pooock 83-6]
[Ford 83]	[Menke 87]	[Pooock 83-7]
[Foster 82]	[Mokhoff 84]	[Pooock 84]
[French 83]	[Moody 85]	[Prasad 87]
[Friedman 84]	[Myers 83]	[Pursley 85]
[Good 84]	[Neil 81]	[Rehsoft 84]

[Salfer 85]	[Siroux 85]	[Viglione 84]
[Santarelli 84]	[Smith 83]	[Viglione 86]
[Schalk 83]	[Smith 84]	[Visser 87]
[Schmandt 85]	[Stephens 83]	[Watrous 85]
[Scott 83]	[Sweeney 86]	[White 84]
[Seaman 82]	[Taylor 86]	[Wood 86]
[Seaman 83]	[Tecosky 86]	[Woods 85]
[Seaman 85]	[Teja 83]	[Wyatt 85]
[Senensieb 84]	[Thompson 84]	[Yellen 83]
[Shapiro 84]	[Thompson 85]	[Zue 84]
[Shapiro 85]	[Underwood 84]	

## **SECTION 2. STRESS RELATED FACTORS**

[Armstrong 80]	[Martin 84]
[French 83]	[Poock 84]

## **SECTION 3. MULTIMODAL FACTORS**

[Armstrong 80]	[Brown 87]	[Salfer 85]
[Berman 84]	[French 83]	

## **SECTION 4. SPEAKER'S EXPERIENCE LEVEL**

[Harrison 84]
[Poock 83-1]

## **SECTION 5. COMPUTER EXPERIENCE LEVEL**

[Epstein 86]	[Poock 83-1]
[Harrison 84]	[Prasad 87]

## **SECTION 6. VOCABULARY FACTORS**

[Cerf-Danon 87]	[Meisel 84]	[Poock 83-6]
[Dillman 84]	[Menke 87]	[Scott 83]
[Ford 83]	[Neil 81]	[Smith 84]
[Kohonen 85]	[Niemann 85]	[Zue 84]
[Meade 85]	[Poock 81-2]	

## APPENDIX C2 ENVIRONMENTAL FACTORS

### SECTION 1. ENVIRONMENTAL FACTORS

[Blunden 80]	[Hunter 85]	[Paddock 83]
[Bristow 86-1]	[Int Res Dev 85]	[Pallett 85]
[Bristow 86-2]	[Int Res Dev 87]	[Pallett 86]
[Brown 87]	[Ivall 86-1]	[Pearkins 84]
[Bruce 82]	[Ivall 86-2]	[Peckham 83]
[Cater 84]	[Joost 83]	[Peckman 86]
[Cavazza 84]	[Kurzweil 86]	[Pfauth 83]
[Cerf-Danon 87]	[Lea 86]	[Philip 87]
[Clements 87]	[LeFever 87]	[Pierrel 87]
[Cochran 83]	[Leggett 82]	[Pister-Bourjot 87]
[Cole 85]	[Llaurado 82]	[Pluhar 83]
[Conrad 83]	[Martin 84]	[Pooock 80]
[Dabbagh 86]	[Martin 86]	[Pooock 83-2]
[EDP Anal 83]	[Mascarenas 84]	[Pooock 83-3]
[Elenius 86]	[Meloni 83]	[Pooock 83-4]
[Elster 80]	[Menke 87]	[Pooock 83-6]
[Eskenazi 83]	[Mokhoff 84]	[Pooock 83-7]
[Fallside 85]	[Moody 85]	[Pooock 84]
[Fallside 86]	[Myers 83]	[Prasad 87]
[Ford 83]	[Neil 81]	[Pursley 85]
[Foster 82]	[Niemann 85]	[Rehsoft 84]
[Friedman 84]	[NTIS 86-1]	[Rollins 85]
[Good 84]	[NTIS 86-2]	[Ross 84]
[GovDatSys 86]	[NTIS 86-3]	[Salfer 85]
[Green 83]	[NTIS 86-4]	[Santarelli 84]
[Green 85]	[NTIS 87-1]	[Schalk 83]
[Hager 86]	[O'Neil 82]	[Schmandt 85]
[Hobbs 84]	[Ogozalek 86]	[Seaman 82]

[Seaman 83]	[Sweeney 86]	[Visser 87]
[Seaman 85]	[Taylor 86]	[Wagner 87]
[Senensieb 84]	[Tecosky 86]	[Watrous 85]
[Shapiro 84]	[Teja 83]	[White 84]
[Shapiro 85]	[Thompson 84]	[Wood 86]
[Siroux 85]	[Thompson 85]	[Woods 85]
[Smith 83]	[Underwood 84]	[Wyatt 85]
[Smith 84]	[Viglione 84]	[Yalabik 84]
[Stephens 83]	[Viglione 86]	[Yellen 83]

## **SECTION 2. MULTILINGUAL FACTORS**

[Eskenazi 83]	[Niemann 85]	[Wagner 87]
[Meloni 83]	[Pister-Bourjot 87]	[Yalabik 84]
[Neil 81]	[Prasad 87]	

## **SECTION 3. MULTICULTURAL FACTORS**

[Eskenazi 83]	[Ogozalek 86]	[Salfer 85]
[Meloni 83]	[Pister-Bourjot 87]	[Wagner 87]
[Neil 81]	[Prasad 87]	[Yalabik 84]
[Niemann 85]		

## **SECTION 4. COMMAND AND CONTROL ENVIRONMENTS**

[Cerf-Danon 87]	[Pfauth 83]	[Poock 83-4]
[Hobbs 84]	[Pister-Bourjot 87]	[Poock 83-6]
[LeFever 87]	[Pluhar 83]	[Salfer 85]
[Neil 81]	[Poock 80]	[Sweeney 86]
[Niemann 85]	[Poock 83-2]	[Yellen 83]

## **SECTION 5. HIGH NOISE ENVIRONMENTS**

[Elster 80]	[Pluhar 83]	[Rehsoft 84]
[Martin 84]	[Poock 83-3]	[Rollins 85]
[Pfauth 83]	[Poock 84]	

## **SECTION 6. LOW-LIGHT ENVIRONMENTS**

[Salfer 85]
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## APPENDIX C3 SITUATIONAL FACTORS

### SECTION 1. SITUATIONAL FACTORS

[Bakst 87]	[GovDatSys 86]	[NTIS 86-4]
[Blunden 80]	[Green 83]	[NTIS 87]
[Bristow 86-1]	[Green 85]	[O'Neil 82]
[Bristow 86-2]	[Hager 86]	[Paddock 83]
[Brown 87]	[Hill 86]	[Pallett 85]
[Bruce 82]	[Hunter 85]	[Pallett 86]
[Cater 84]	[Int Res Dev 85]	[Pearkins 84]
[Cavazza 84]	[Int Res Dev 87]	[Peckham 83]
[Cerf-Danon 87]	[Ivall 86-1]	[Peckman 86]
[Clements 87]	[Ivall 86-2]	[Philip 87]
[Cochran 83]	[Joost 83]	[Pierrel 87]
[Cole 85]	[Kohonen 85]	[Pister-Bourjot 87]
[Connolly 86]	[Kurzweil 86]	[Pluhar 83]
[Conrad 83]	[Lea 86]	[Pooock 80]
[Dabbagh 86]	[LeFever 87]	[Pooock 83-7]
[Damper 84]	[Leggett 82]	[Pooock 84]
[Damper 85]	[Llaurado 82]	[Prasad 87]
[EDP Anal 83]	[Maenobu 84]	[Pursley 85]
[Eleuius 86]	[Martin 86]	[Rehsoft 84]
[Elster 80]	[Mascarenas 84]	[Salfer 85]
[Eskenazi 83]	[Menke 87]	[Santarelli 84]
[Fallside 85]	[Mokhoff 84]	[Schalk 83]
[Fallside 86]	[Moody 85]	[Schmandt 85]
[Fisher 86]	[Myers 83]	[Seaman 82]
[Ford 83]	[Neil 81]	[Seaman 83]
[Foster 82]	[NTIS 86-1]	[Seaman 85]
[Friedman 84]	[NTIS 86-2]	[Senensieb 84]
[Good 84]	[NTIS 86-3]	[Shapiro 84]

[Shapiro 85]	[Thompson 84]	[White 84]
[Siroux 85]	[Thompson 85]	[Williams 85]
[Smith 83]	[Underwood 84]	[Wood 86]
[Stephens 83]	[Viglione 84]	[Woods 85]
[Taylor 86]	[Viglione 86]	[Wyatt 85]
[Tecosky 86]	[Visser 87]	[Yellen 83]
[Teja 83]	[Watrous 85]	

## **SECTION 2. MULTIUSER OR GROUP USAGE**

[Cerf-Danon 87]	[Maenobu 84]	[Pooch 80]
[Connolly 86]	[Neil 81]	[Prasad 87]
[Eskenazi 83]	[Pister-Bourjot 87]	[Salfer 85]
[Kohonen 85]	[Pluhar 83]	[Yellen 83]
[LeFever 87]		

## **SECTION 3. INDIVIDUAL USAGE**

[Pister-Bourjot 87]  
[Hill 86]

## **SECTION 4. HANDICAP SITUATIONS**

[Damper 84]	[Fisher 86]
[Damper 85]	[Kurzweil 86]

## APPENDIX C4 QUANTITATIVE FACTORS

### SECTION 1. QUANTITATIVE FACTORS

[Anatharaman 86]	[Gould 83]	[Moody 85]
[Baker 84]	[GovDatSys 86]	[Myers 83]
[Bisiani 84]	[Green 83]	[NTIS 86-1]
[Blunden 80]	[Green 85]	[NTIS 86-2]
[Bristow 86-1]	[Gubrynowicz 84]	[NTIS 86-3]
[Bristow 86-2]	[Hager 86]	[NTIS 86-4]
[Brown 87]	[Harrison 84]	[NTIS 87-1]
[Bruce 82]	[Hill 86]	[O'Neil 82]
[Calcaterra 82]	[Hobbs 84]	[Paddock 83]
[Cater 84]	[Hunter 85]	[Pallett 85]
[Cavazza 84]	[Int Res Dev 85]	[Pallett 86]
[Clements 87]	[Int Res Dev 87]	[Pearkins 84]
[Cochran 83]	[Ivall 86-1]	[Peckham 83]
[Cole 85]	[Ivall 86-2]	[Peckman 86]
[Conrad 83]	[Johnson 86]	[Pfauth 83]
[Dabbagh 86]	[Joost 83]	[Philip 87]
[Dillman 84]	[Koelsch 87]	[Pierrel 87]
[EDP Anal 83]	[Kurzweil 86]	[Pluhar 83]
[Elenius 86]	[Lea 86]	[Pooch 83-1]
[Elster 80]	[LeFever 87]	[Pooch 83-7]
[Epstein 86]	[Leggett 82]	[Pooch 84]
[Fallside 85]	[Llaurado 82]	[Pooch 85]
[Fallside 86]	[Lombardo 84]	[Pursley 85]
[Ford 83]	[Martin 84]	[Reardon 87]
[Foster 82]	[Martin 86]	[Rehsoft 84]
[French 83]	[Mascarenas 84]	[Saitta 83]
[Friedman 84]	[Meisel 84]	[Santarelli 84]
[Good 84]	[Mokhoff 84]	[Schalk 83]

[Schmandt 85]	[Smith 83]	[Underwood 84]
[Scott 83]	[Smith 84]	[Viglione 84]
[Seaman 82]	[Stephens 83]	[Viglione 86]
[Seaman 83]	[Sweeney 86]	[Visser 87]
[Seaman 85]	[Taylor 86]	[Watrous 85]
[Senensieb 84]	[Tecosky 86]	[White 84]
[Shapiro 84]	[Teja 83]	[Wood 86]
[Shapiro 85]	[Thompson 84]	[Woods 85]
[Siroux 85]	[Thompson 85]	[Wyatt 85]

## **SECTION 2. TIME**

[Anatharaman 86]	[Dillman 84]	[Hill 86]
[Brown 87]	[Epstein 86]	[Scott 83]

## **SECTION 3. ACCURACY**

[Calcaterra 82]	[Elster 80]	[Koelsch 87]
[Dillman 84]	[French 83]	[Meisel 84]

## **SECTION 4. SPEED OF ENTRY**

[Anatharaman 86]	[Dillman 84]	[Meisel 84]
[Bisiani 84]	[Hill 86]	[Sweeney 86]

## **SECTION 5. EASE OF USE**

[Epstein 86]

## **SECTION 6. PRODUCTIVITY**

[Hager 86]  
[Pfauth 83]  
[Reardon 87]

## APPENDIX C5 TRAINING FACTORS

### SECTION 1. TRAINING FACTORS

[Anisworth 84]	[Elster 80]	[Kurzweil 86]
[Baker 84]	[Epstein 86]	[Lea 86]
[Banatre 83]	[Fallside 85]	[Leggett 82]
[Biermann 85-2]	[Fallside 86]	[Levinson 86]
[Blunden 80]	[Ford 83]	[Llaurado 82]
[Bridle 83]	[Foster 82]	[Lombardo 84]
[Bristow 86-1]	[French 83]	[Longuet-Higgins 85]
[Bristow 86-2]	[Friedman 84]	[Mackie 87]
[Brown 87]	[Frison 84-1]	[Maenobu 84]
[Bruce 82]	[Frison 84-2]	[Martin 86]
[Calcaterra 82]	[Good 84]	[Mascarenas 84]
[Cater 84]	[GovDatSys 86]	[Mavaddat 85]
[Cavazza 84]	[Green 83]	[Meade 85]
[Cerf-Danon 87]	[Green 85]	[Meisel 84]
[Clements 87]	[Gubrynowicz 84]	[Meloni 83]
[Cochran 83]	[Hager 86]	[Meloni 87]
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New York, New York 10010

Strategic, Inc.  
4320 Stevens Creek Blvd. Suite 215  
San Jose, California 95129

Tab Books  
Monterey & Pinola Avenues  
Blue Ridge Summit, Pennsylvania 17214

UMI Research Press  
300 N. Zeeb Rd.  
Ann Arbor, Mississippi 48106

## APPENDIX E CURRENT VOICE RECOGNITION SYSTEMS

### AMDAHL COMMUNICATIONS SYSTEMS DIVISION

2200 N. Greenville  
Richardson, Texas 75081  
(214) 699-9500

F2211-45 Two Channel: Voice Input/Output (for PBX)

### ARTICULATE SYSTEMS INCORPORATED

2380 Ellsworth St.  
Berkley, California 94704  
(415) 549-1013

Voice Navigator SR System (for MAC +, SE, II)

### AT&T CONVERSANT SYSTEMS

6200 E. Broad St.  
Columbus, Ohio 43213  
(614)860-3836 or 1(800)341-2272

Conversant 1(tm) Voice System: Voice Input/Output (for Touchtone data input)

### CONVERGENT TECHNOLOGIES, INC.

2700 N. First St., P.O. Box 6685  
San Jose, California 95150-6685  
(408)434-2848

Voice Master: Voice Input/Output (for Convergent Technologies; The Bell 212-A; AT&T Dimension; Rolm CBX; Northern Telecom SL-1)

### COVOX, INC.

675 D Conger St.  
Eugene, Oregon 97402  
(503)342-1271

Voice Master: Voice Input/Output (for IBM; Commodore 64; Apple & Atari)

### DRAGON SYSTEMS INCORPORATED

Chapel Bridge Park  
55 Chapel St.  
Newton, Massachusetts 02158

**KEYTRONIC CORPORATION**

P.O. Box 14687  
Spokane, Washington 99214  
1(800)262-6006

Keytronics Model KB5152V (for IBM PC XT)

**HARRIS/LANIER**

1700 Chantilly Dr., NE  
Atlanta, Georgia 30324  
(404)329-8000 or 1(800)241-1706

System IV(Digital Dictation): Voice Input (for Lanier Business Products)

**HEWLET-PACKARD CO.**

3000 Hanover St.  
Palo Alto, California 94304  
(415)857-1501

Office Talk: Voice Input/Output (for IBM, HP Vectra)

**IBM (INTERNATIONAL BUSINESS MACHINES)**

Old Orchard Rd.  
Armonk, New York 10504  
(914)765-1900

Juniper II: Voice Input/Output (for IBM)

Model 6294-771: Voice Input/Output (for IBM)

PS/2 Speech Adapter: Voice Input/Output (for IBM)

**INERSTATE VOICE PRODUCTS**

1849 W. Sequoia Ave.  
Orange, California 92668  
(714)937-9010

CSRB240(Connected Speech Recognition Board): Voice Input (for IBM)

LC-SRB (Low-Cost Speech Recognition Board): Voice Input (for IBM)

Systems 300: Voice Input (for RS 232C)

S4000 (Continuous Speech Voice Data Entry Peripheral): Voice Input (for IBM)

VocaLink Cellular Module: Voice Input (for Mitsubishi; OKI; NEC)

VRC 008: Voice Input (for TTL)

VRT 300: Voice Input (for DEC; CIE Terminals; Plessey Peripheral; RS-232C)

**KURZWEIL APPLIED INTELLIGENCE, INC.**

411 Waverley Oaks Rd.  
Waltham, Massachusetts 02154-8465  
(617)893-5151

KVS (Kurzweil Voicesystems): Voice Input (for IBM PC, XT, AT)

KVT (Kurzweil Voiceterminal): Voice Input (for DEC; IBM; Hewlett-Packard)

**MICROLOG CORP.**

20270 Goldenrod Lane  
Germantown, Maryland 20874  
(301)428-3227 or 1(800)635-3355

VoiceConnect System 3000, 3500: Voice Input/Output (for IBM PC, XT, AT)

**MICROPHONICS TECHNOLOGY CORP.**

25 37th St. NE, Suite B  
Auburn, Washington 98002  
(206)939-2321 or 1(800)325-9206

Pronounce Voice Control System: Voice Input (for IBM)

**MIMIC, INC.**

P.O. Box 705  
Islington, Massachusetts 02090-0705  
(617)329-9593

Mimic Speech Processor: VOIS (Voice Output for Industrial Systems):  
Voice Input/Output (for OEM; Microcomputer)

**NEC AMERICA, INC.**

Radio & Transmission Division  
2740 Prosperity Ave.  
Fairfax, Virginia 22031  
(703)698-5540

AR-10: Voice Input/Output (for IBM)

DP-200: Voice Input (for RS-232C; RS-422; IEEE-48; 20MA Current loop)

SAR-10: Voice Input/Output (for IBM)

SR-10: Voice Input (for RS-232C)

SR-100: Voice Input (for RS-232C; NEC)

**PERIPHONICS CORP.**

4000 Veterans Memorial Hwy.  
Bohemia, New York 11716  
(516)467-0500

TeleMarketer: Voice Input (for CDC; DG; DEC; HIS; IBM; NCR; Unisys; Wang; PABX; ACD)

VoicePac Announcement System: Voice Input/Output (for CDC; DG; DEC; HIS; IBM; NCR; Unisys; Wang; PABX; ACD)

**SCOTT INSTRUMENTS CORP.**

1111 Willow Springs Dr.  
Denton, Texas 76205  
(817)387-9514

Coretechs VET-3 Voice Entry Terminal: Voice Input/Output (for RS-232C)

Shadow/VET Voice Entry Terminal: Voice Input (for Apple)

VET-2 Voice Entry Terminal: Voice Input (for Apple)

**SHURE BROTHERS, INC.**

222 Hartrey Ave.  
Evanston, Illinois 60202-3696  
(312)866-2200

SM10 Headset Microphone: Voice Input (for OEM)

VR 230 Two Way Headset: Voice Input/Output (for OEM)

VR300 Gooseneck Microphone: Voice Input (for OEM)

503BG Close-Talk Microphone: Voice Input (for OEM)

512 Two Way Headset: Voice Input/Output (for OEM)

**SPEECH, LTD.**

3790 El Camino Real, Suite 213  
Palo Alto, California 94306  
(415)858-2207

Protalker: Voice Input/Output (for IBM; OEM; Microcomputer)

**SPEECH SYSTEMS, INC.**

18356 Oxnard St.  
Tarzana, California 91356  
(818)881-0885

DS100 Phonetic Engine: Voice Input (for RS-232C)

PE200Phonetic Engine: Voice Input (for IBM; RS232C)

SUDBURY SYSTEMS, INC.  
31 Union Ave.  
Sudbury, Massachusetts 01776  
(617)443-8966 or 1(800)245-7817

RTAS: Voice Input/Output

SUNCOAST SYSTEMS, INC.  
3100 McCormick St.,  
Suite 22, P.O. Box 7105  
Pensacola, Florida 32514  
(904)478-6477 or 1(800)843-9363

Computerfone: Voice Input/Output (for OEM)

TECMAR, INC.  
6225 Cochran Rd.  
Solon, Ohio 44139  
(216)349-1009

Voice Recognition Board: Voice Input (for IBM PC)

TEXAS INSTRUMENTS, INC.  
P.O. Box 655012  
Dallas, Texas 75265  
1(800)527-3500

Speech Command System: Voice Input/Output (for IBM; TI)

VOICE COMPUTER TECHNOLOGIES CORP.  
5730 Oakbrook Pkwy  
Norcross, Georgia 30093-1888  
(404)441-2303

VCT Series 2000 Model 2016: Voice Input/Output (for CDC; DG; DEC;  
HIS; IBM; NCR; Unisys; Microcomputer)

THE VOICE CONNECTION  
17835 Sky Park Circle, Suite C  
Irvine, California 92714  
(714)261-2366

IntroVoice I: Voice Input (for Apple II, Apple IIe; RS-232C)

IntroVoice II: Voice Input (for Apple)

IntroVoice III: Voice Input (for IBM PC, XT, AT)

IntroVoice V: Voice Input (for IBM; Compaq 386)

IntroVoice VI: Voice Input (for IBM PS/2, PC, XT, AT; Compaq 386)

PVDL (Portable Voice Data Logger): Voice Input/Output (for IBM)

VMC 2020: Voice Input (for Apple II, IIe)

**VOICE INDUSTRIES CORP. (VERBEX)**

10 Madison Ave.

Morristown, New Jersey 07960

(201)267-7505

Series 4000; 5000: Voice Input (for RS-232C)

**VOTAN**

4487 Technology Dr.

Fremont, California 94538

(415)490-7600

Voice Management System: Voice Input/Output (for RS-232C;  
Centronics parallel)

Votan Voice Card (Board Level): Voice Input/Output (for IBM)

VSP 1000 (Board Level): Voice Input/Output (for IEEE-786)

VTR 3270: Voice Input/Output (for IBM; Coax

VTR-6050 Series II: Voice Input/Output (for RS-232C)

**VYNET CORP.**

180 Knowles Dr.

Los Gatos, California 95030

(408)370-0555; (408)370-9764; or

1(800)538-7002

V2100 Telephone Voice Response System: Voice Input/Output (for IBM)

V2301/V1202/V2202 Telephone Speech Digitizer & Playback:

Voice Input/Output (for IBM)

V4000 Telephone Voice Response System: Voice Input/Output (for IBM)

**XTRA BUSINESS SYSTEMS**

2350 Qume Dr.

San Jose, California 95131

(408)945-8950

Voice Communications System: Voice Input/Output (for XTRA Series)

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